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PART V - RED RIVER OF THE NORTH

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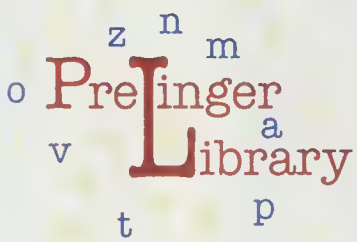

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PART V—RED RIVER OF THE NORTH

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AUGUST 1937

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NATIONAL RESOURCES COMMITTEE

INTERIOR BUILDING

WASHINGTON

August 21, 1937.

The PRESIDENT,
The White House,
Washington, D. C.

MY DEAR MR. PRESIDENT:

We have the honor to transmit herewith the Report on Regional Planning in the Valley of the Red River of the North, which constitutes Part V of the series of reports on Regional Planning activities and progress. This report, prepared by an interstate commission with the assistance of consultants from our Water Resources Committee, illustrates the possibilities of cooperation through planning for joint attack on interstate problems.

Sincerely yours,

HAROLD L. ICKES,
Secretary of the Interior, Chairman

HARRY H. WOODRING,
Secretary of War.

HENRY A. WALLACE,
Secretary of Agriculture.

DANIEL C. ROPER,
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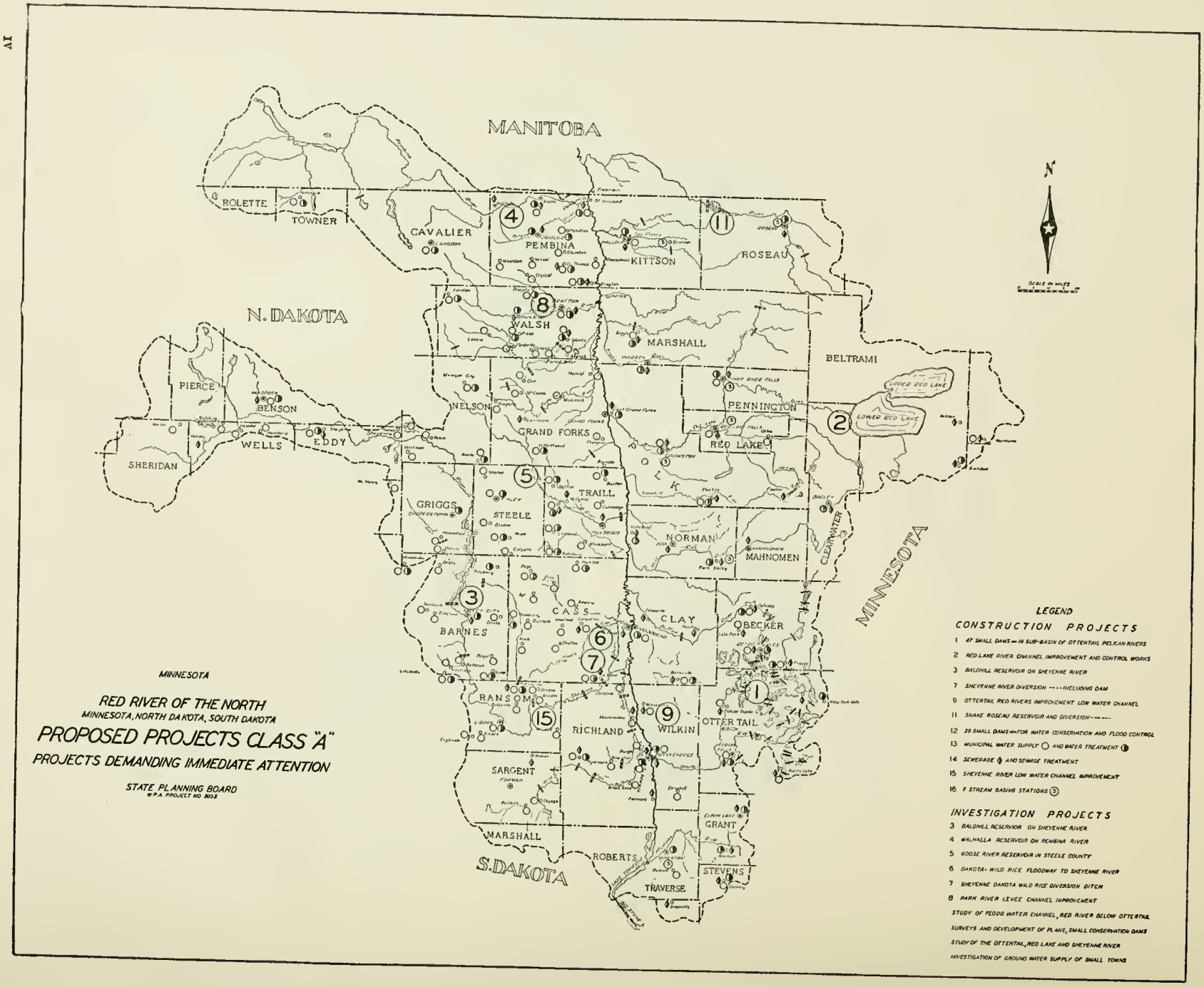
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S. DAKOTA
N
SCALE IN MILES
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2 RED LAKE RIVER CHANNEL IMPROVEMENT AND CONTROL WORKS
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REGIONAL PLANNING—PART V
RED RIVER OF THE NORTH

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DEAN HOLM, *Executive Secretary*, Interstate Committee

FOREWORD

By the Water Resources Committee

In the Valley of the Red River of the North, a critical situation is being met through interstate cooperation and regional planning. After successive years of lack of agreement on any joint plan of action, the States of Minnesota, North Dakota, and South Dakota with Federal assistance have:

1. Made surveys and investigations—gathered the facts.

2. Prepared a plan for the full use of the water resources of the basin.

3. Made a program of projects to carry out the plan over a term of years.

4. Made a substantial start in actual construction according to the plan and

5. Adopted an interstate compact creating an interstate agency to administer the plan.

The problem in the valley of the Red River of the North is primarily a question of water. In 1916–19 there were floods to contend with, from 1930–35 drought threatened the water supply of cities and farms. Either or both may recur. Each of the three State planning boards could make plans within their respective States, but the waters flowing through this former wheat kingdom and present rich agricultural area paid no attention to State boundaries. The cities dependent on the river for their water supply are located on both sides of the main stream which forms the political boundary line.

During 5 years of drought and critical water shortage, public works proposals in the basin of the Red River of the North were concentrated on water conservation and urban water supply. Federal assistance was given to projects for the extension of water treatment plants and for sewage treatment but major projects intended to conserve water and bring it to the cities failed of approval—in spite of the fact that the Minnesota Economic Council had set up a fund of about half a million dollars to help defray the cost. Some meritorious projects were not undertaken because of the absence of legally authorized local groups with which the Federal Government might deal. Moreover, much time and energy were spent in discussion of unwise or patently uneconomic proposals. Thus, although the drought conditions aroused intense interest in the water problems of the basin, a plan for water conservation and a mechanism for carrying it out were lacking.

In July 1935, the Governors of Minnesota, North Dakota, and South Dakota called an interstate conference in Fargo, N. Dak., to consider the critical water problems of the basin. This conference agreed that a coordinate water plan covering the entire drainage area should be formulated as a necessary preliminary to effective action. The organization to undertake the studies essential to such a plan was authorized at a second conference in November 1935, which set up an interstate committee. This interstate committee consisted of the chairmen of the three State planning boards and H. H. Barrows and W. W. Horner as consultants for the National Resources Committee.

Headquarters for the committee were set up in St. Paul, and the work was carried on through the staffs of the State planning boards. Committee meetings were attended by interested State and local officials who gave the fullest cooperation. Specific studies were undertaken by the water engineers and sanitary engineers of the several States, who also reviewed basic hydrologic data and brought them up to date.

Accompanied by State officials and water engineers the committee made an extended inspection of the basin in the spring of 1936. Meetings were held each night at which local problems were presented in detail by local men and the work of the committee was discussed by one of its members. Throughout the study effective assistance was rendered the committee not only by State agencies but also by such Federal agencies as the Corps of Engineers and the United States Geological Survey. When the committee needed to ascertain probable evaporation losses from certain proposed reservoirs during long periods of drought the services of Adolph Meyer were secured as an additional consultant.

Before its studies were completed the committee prepared in July 1936 a preliminary report to clarify certain project proposals then deemed critically important. Its general studies were concluded during the latter half of the year and its comprehensive report was filed with the State planning boards and with the National Resources Committee in December. An immediate result of its earlier report was an allocation by the Works Progress Administration of $50,000 to the Corps of Engineers for a detailed analysis of several important projects.

The study on which the report is based was unique in several respects. It was primarily an interstate enterprise, most of the work being accomplished through the joint efforts of local and State officials in the three States. It resulted in the first comprehensive water conservation program for any large drainage basin in the United States. Many of the investigation projects

and construction projects that were recommended have been completed or initiated since the first draft of the report was circulated.

It has been determined that the major water problem of the area is the conservation of run-off in lakes and reservoirs and its release to stream channels at a rate which will provide a dependable supply at the principal cities. The coordinated water plan of the committee was formulated with this prime objective constantly in view.

The plan involves an increase in effective storage in the lakes of the Otter Tail River system. By controlling the levels of these lakes at slightly greater heights, a largely increased storage of ground water seems possible. The plan provides for a somewhat similar improvement in the use of the Red Lake storage, and for construction of a large dam on the Sheyenne and possibly of dams on other streams on the Dakota side. Small dams are proposed on various normally dry channels to impound water for stock and to meet other rural needs.

The plan takes into account not only seasonal regulation of the streams, but also the possibility of a long-time carry-over in storage to meet the needs of drought years. Particular consideration is given to the stabilization of lake levels, in order not to impair the high recreational value of the lakes.

An important phase of the plan is the improvement of the stream channels for the purpose of reducing losses of water in transit. Such losses are now extremely high in the basin; flows of as much as 30 cubic feet per second in the Otter Tail River, for example, may be dispersed before reaching Fargo.

While the disastrous floods of 1916–19 in the drainage area have been nearly or quite forgotten, the interstate committee is convinced of the probable occurrence of floods there from time to time in the future, and its plan contains provision for flood-flow correction. It also gives consideration to the improvement in water power possibilities that will result from regulation of stream flow.

As the execution of the plan should reduce the flood flows and augment the low flows of the Red River of the North at the Canadian border, the plan should not create any controversial international questions.

The report recognizes the interstate character of the problems of the basin and the necessity for a carefully formulated and unified program of operation. It includes a scheme for an interstate authority with power to control the water resources of the area and to levy limited assessments on the beneficiaries. The attorneys general of the three States prepared enabling acts, which have received action during the 1937 sessions of the legislatures.

Although the action of the Minnesota Legislature somewhat restricted the scope of the compact, the interstate compact commission has now been established. As its usefulness is demonstrated, it is reasonable to expect that the whole drainage basin will be brought within its jurisdiction. It is hoped by the Water Resources Committee that the interstate commission will:

1. Propose such further investigations as may be desirable for crystallization of the various parts of the plan and to arrange for prosecution of these investigations in part through its own organization and in part through cooperation with appropriate State and Federal agencies.

2. Arrange, through its own administration or through other governmental agencies, for the preparation of detailed designs and specifications and the orderly construction of the various projects entering into the plan as a whole, including necessary agreements for the distribution of costs and the specific arrangements involved in the financial program.

3. Establish a permanent system of operation and maintenance which will insure, from year to year, the integrated functioning of all parts of the plan.

REPORT OF THE

INTERSTATE COMMITTEE

ON THE

RED RIVER OF THE NORTH

•

APRIL 1937

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Civil Engineering Department
University of Minnesota

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Public Works Administration

D. G. Miller
Senior Drainage Engineer
Bureau of Agricultural Engineering
U. S. Department of Agriculture

Raphael Van Neste
District Engineer
Works Progress Administration

THE INTERSTATE COMMITTEE

ON THE

RED RIVER OF THE NORTH

ST. PAUL, MINNESOTA

April 6, 1937

Mr. ABEL WOLMAN, *Chairman*,
Water Resources Committee,
Interior Building,
Washington, D. C.

DEAR MR. WOLMAN:

We have the honor of presenting herewith the report of the Interstate Committee on the Red River of the North Drainage Basin.

Practically all of the water problems of this area are of long standing—many of them dating back 35 or more years. As each of these problems arose, a special group was organized to study the problem and appeal to the State and Federal Governments for assistance. There was little coordination of effort among these groups and very little or nothing has been accomplished to improve the situation as a whole.

This report is the first attempt to treat jointly the problems of conservation and transportation of water, pollution and flood control of the Red River of the North Drainage Basin. Local, county, State, and Federal authorities have rendered valuable assistance in the preparation of the report, and it is hoped that it will serve as a means of coordinating the efforts of all the people living in this area.

Sincerely yours,

H. H. BARROWS
JAMES P. CAIN
W. W. HORNER
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IRVIN LAVINE
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CHARLES W. PUGSLEY
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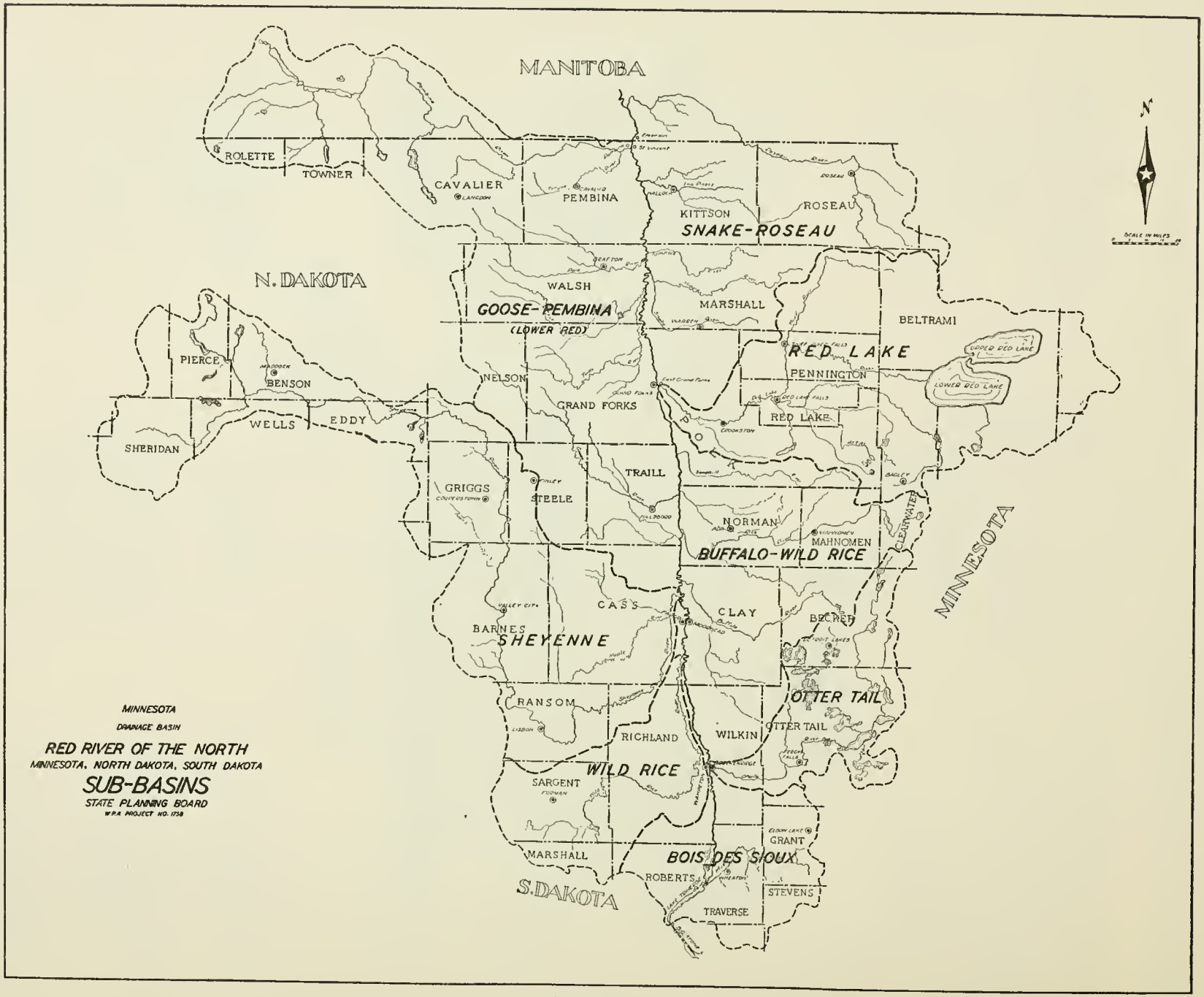
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GOOSE-PEMBINA
(LOWER RED)
MARSHALL
BELTRAMI
RED LAKE
PENNINGTON
RED LAKE
PIERCE
BENSON
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MINNESOTA
CASS
CLAY
BECKER
BARNES
SHEYENNE
RANSOM
OTTER TAIL
OTTER TAIL
RICHLAND
WILKIN
WILD RICE
SARGENT
GRANT
MARSHALL
BOIS DES SIOUX
ROBERTS
S.DAKOTA
STEVENS
TRAVERSE
MINNESOTA
DRAINAGE BASIN
RED RIVER OF THE NORTH
MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA
SUB-BASINS
STATE PLANNING BOARD
W.P.A. PROJECT NO. 1758
N

FIGURE 1

STAFF REPORT—SECTION I
PHYSICAL CHARACTERISTICS AND CLIMATOLOGY

Physical Characteristics

The basin of the Red River of the North is situated almost exactly in the geographic center of the North American Continent. The approximate total drainage area of the Red River at the point where it crosses the international boundary into Canada is 35,520 square miles. Of this, 670 square miles are in South Dakota, 16,800 square miles in North Dakota, 16,090 square miles in Minnesota, and 1,960 square miles in Canada along the upper Pembina River. The Roseau River at the boundary drains an area of 1,300 square miles in Minnesota and 370 square miles in Canada. The Souris River, a tributary of the Assiniboine River in Canada, makes a loop through north central North Dakota and drains an area of 8,766 square miles in that State. The Assiniboine River, in turn, empties into the Red River near Winnipeg, Canada. The part of the Red River Basin south of the international boundary is approximately 245 miles long and 300 miles wide at its widest point.

The beginning of the Red River of the North is at Wahpeton, N. Dak., where the Bois des Sioux and the Otter Tail Rivers join. From this point to the international boundary, a distance of about 190 miles, the river follows a course practically directly northward, there being only a slight deviation toward the west. From the outlet of Lake Traverse, the headwaters of the Bois des Sioux, the stream follows a winding course through the valley into Lake Winnipeg. The distance from Wahpeton to the international boundary is 394 miles, or practically twice the airline distance between the two points. The fall, in general, is slight and diminishes toward the north. The surface altitudes above mean sea level are: 980 feet at Lake Traverse; 963 feet at Wahpeton; 900 feet at Fargo; 830 feet at Grand Forks; 789 feet at the international boundary; and 755 feet at Winnipeg.

Tributaries of Red River

The principal tributaries entering the Red River below the point of confluence of the Otter Tail and Bois des Sioux Rivers on the Minnesota side are the Pelican, Buffalo, Wild Rice, Red Lake, Tamarac, and Two Rivers. The Roseau River, although it rises in Minnesota, discharges into the Red River in Canada. On the North Dakota side the principal tributaries are the Wild Rice, Sheyenne, Maple, Goose, Park, and Pembina Rivers. The Pembina River has its source and much of its drainage area in Canada. There are a number of other smaller streams that have some significance.[1] Figure 1 shows the outline of the basins of the Red River and its principal tributaries. The drainage basin of the Red River in the United States consists of a broad plain with a slight slope toward the Red River flanked on both the east and west sides by relatively steep slopes followed by higher lands. The character of these slopes and higher lands varies on opposite sides of the valley and from north to south.

The highest point of the drainage area, located in Marshall County, S. Dak., near the southernmost extreme of the basin is at an elevation of about 1,850 feet; while the lowest point, the water surface of the river as it enters Canada, is at elevation 789. Most of the region is below elevation 1,200.

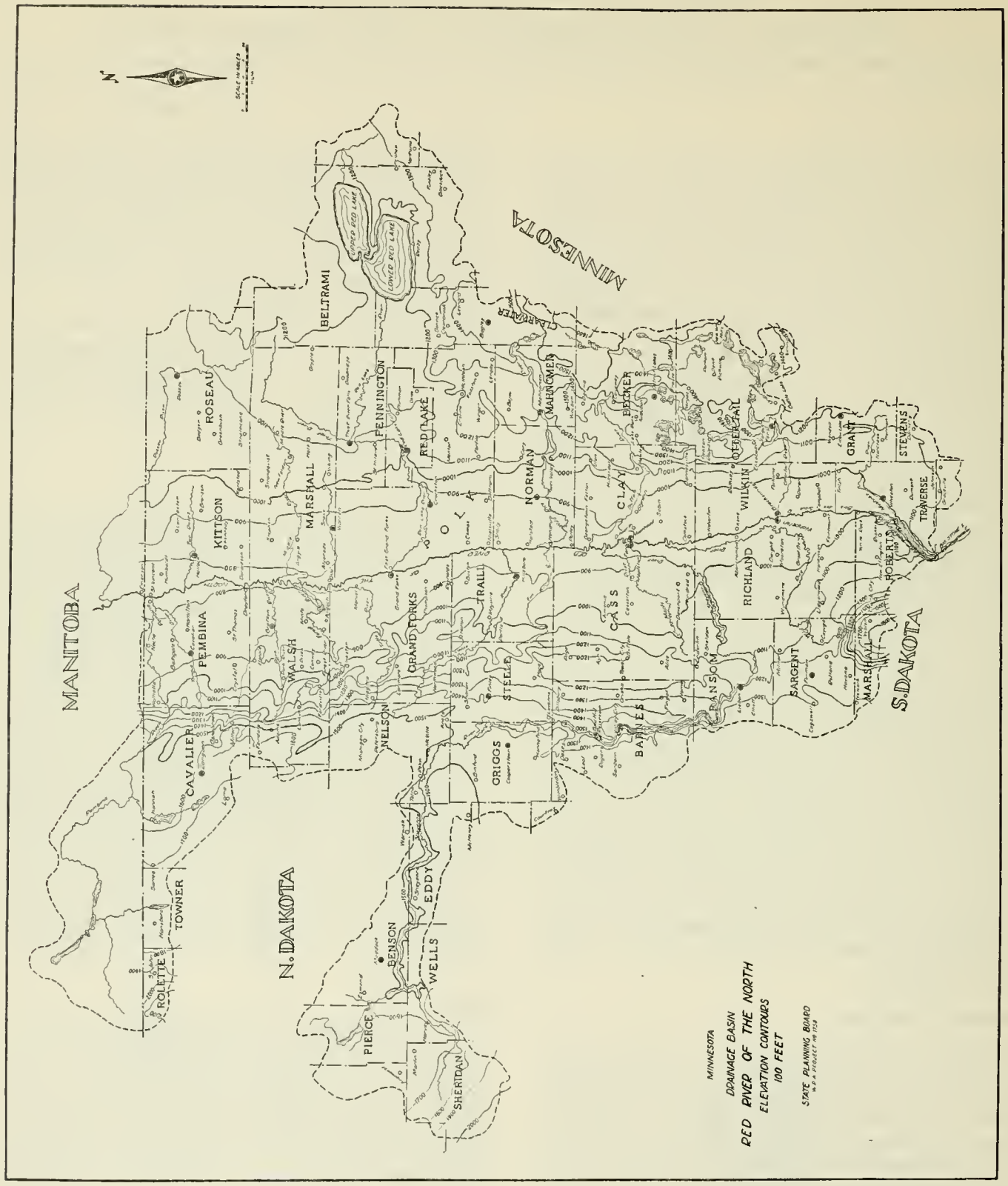
Topography

A cross section of the valley at Wahpeton shows an average rise of about 3⅔ feet per mile away from the river on the North Dakota side and about 12½ feet per mile on the Minnesota side. In North Dakota there is a gentle and almost uniform slope upward until the drainage divide is reached whereas in Minnesota the terrain is very rough, with a large number of lakes in the outer portion of the drainage area. A cross section at Grand Forks shows more uniformity for the two sides of the valley, although the rough terrain and lakes are also present on the Minnesota side. Near the international boundary the valley is broader extending to a distance of about 80 miles to the east in Minnesota and about 35 miles to the west in North Dakota. East of the Red River the land is level and poorly drained and most of it is marshy and unfit for agriculture. On the west, the gently sloping valley terminates with an abrupt rise into the Pembina Mountains. Figure 2 shows the topography of the basin to a 100-foot contour interval.

Geology

The geologic history of the Red River Valley explains many of its peculiar characteristics. As the front of the last (late Wisconsin) glacier of the great Pleistocene ice age retreated to the north, the depression, in which the Red River Valley now lies, was exposed. This depression was much shallower than the earlier preglacial depression for the ice had deposited glacial boulder clay in it to a depth of up to 400 feet.

[1] Other streams in the Red River drainage area are the Mustinka River, the Sand Hill River, the Pelican and Toad Rivers tributary to the Otter Tail River, and the Clearwater and Thief Rivers tributary to the Red Lake River. All of these streams are in Minnesota.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GRIGGS
EDDY
WELLS
BENSON
PIERCE
SHERIDAN
MINNESOTA
DRAINAGE BASIN
RED RIVER OF THE NORTH
ELEVATION CONTOURS
100 FEET
STATE PLANNING BOARD

FIGURE 2

The valley had sloped to the north and as soon as the ice front had retreated northward a lake formed between the ice and natural barrier found to the south. The lake gradually became larger as the ice continued to retreat northward and at one stage it was approximately 700 miles long and 250 miles wide at the international boundary.

This great lake has been named Lake Agassiz in honor of Louis Agassiz. Lake Agassiz at first drained to the south through the channel now occupied by Lakes Traverse and Bigstone and the Minnesota River. Melting of the ice blockade to the north eventually opened other lower outlets which drained the lake with the exception of the large Manitoba Lakes which have remained as remnants of glacial Lake Agassiz. The lake level was lowered in a series of stages, each stage being marked by a beach produced by wave action.

These beaches are still readily discernible as low gravel and sand ridges rising above the plain. They can be traced for many miles. The western margin of the lake was formed by the Pembina escarpment in North Dakota. This escarpment is composed of upper cretaceous shales and was formed by preglacial erosion of the valley to the east. Lake Agassiz received its water directly from the melting ice and from rivers which flowed into it. These rivers were the Sheyenne, the Elk, and the Pembina. These rivers together with the water direct from the ice carried large quantities of sand, gravel, silt, and clay into the lake.

Delta Formation

Each of the rivers formed a delta of the coarser material in the lake close to their mouths while the finer material was carried farther into the lake to be deposited as fine silt and clay which covered the irregularities of the original lake floor and produced the present very level Red River plain. East and west portions of the present watershed of the Red River outside the valley proper contain great numbers of lakes of glacial origin. The old lake bottom itself contains a few large lakes among which is Red Lake.

During the earlier stages of the lake the Sheyenne River entered it several miles south of Lisbon, N. Dak., and formed its broad sandy delta. When the lake was lowered below the old river mouth the Sheyenne began to cut a channel across its own delta. In doing this, it turned to the north, finally joining the Red River which had begun to cut its own channel as soon as the lake had disappeared.

The Red River and its tributaries are very youthful streams though they have winding channels which are characteristic of old age. This, however, was due to the cutting of their channels on the very flat lake bottom.

The spacing of the tributaries of the Red River seems to have been determined by the streams which entered the valley as the water of the lake receded. All of the perennial streams tributary to the Red River have their sources outside the area of ancient Lake Agassiz, and most of them show every evidence of having been much larger. They have few affluents and usually receive the drainage from only a narrow area on both sides. As a result, broad areas between the rivers have little or no definite drainage. The only drainage ways in the areas between the principal rivers are coulees from 20 to 40 feet deep near the river and a mile or two in length. These carry water only after heavy rains or while the snow is melting, remaining dry at other times. This arrangement of the streams is due to the extreme youth of the drainage system.

Soils

The soils throughout the former glacial lake bed are deep, heavy, finely divided, well-compacted mixtures of clay, loam, and small proportions of very fine sand. For the first foot or more this mixture is blackened by decayed organic matter. The soils of the valley are classified by the United States Bureau of Soils (Bull. 96, 1913) as the Fargo series of soils. Six types are mentioned: Clay loam, fine sandy loam, loam, fine sand, clay, and silt loam. In their natural condition most of these soils are poorly drained. When properly drained they are very well suited to agricultural purposes because they are very fertile. The soil along the upper reaches of the watershed is not so uniform but most of it can be developed into excellent farm land. Figure 3 shows the location of the principal soil types of the basin.

Climatology

The climate of the basin of the Red River of the North is temperate and continental having cold winters and warm summers. The prevailing winds are northwesterly and the area is in the northern path of eddying cyclones that move eastward. There is no marked difference in elevation in the area with the result that there is a geographical uniformity of climate.

Temperature Range

Temperatures of 85° to 95° Fahrenheit are common in the summer as are 25° and 35° below zero in the winter. Extreme temperatures of −50° and 110° Fahrenheit have been recorded in the basin. These extremes of temperature are not felt as much in the regions where the relative humidity is higher. Humidity data for three stations in this area are tabulated in table 1.

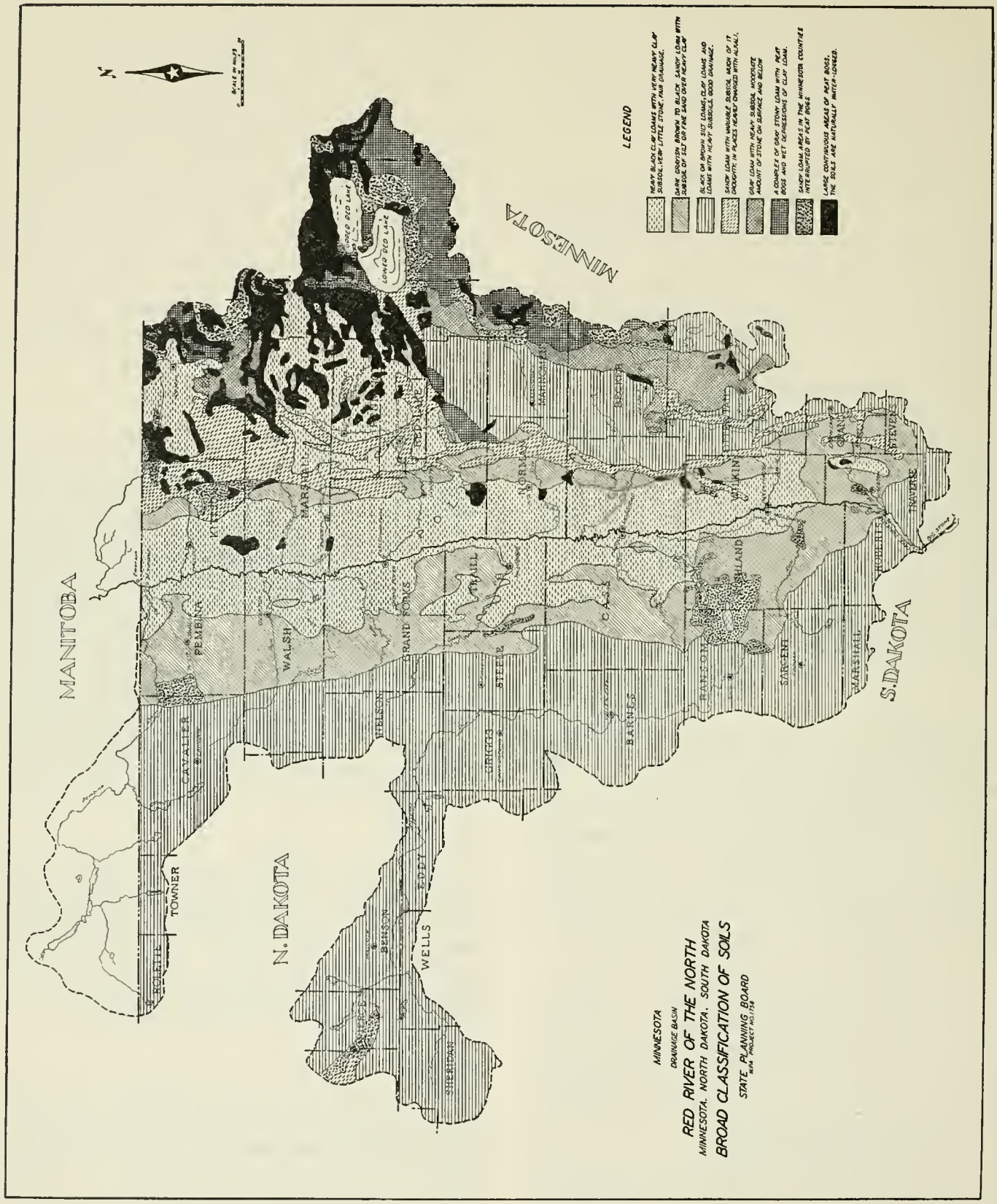

MANITOBA
MINNESOTA
N. DAKOTA
S. DAKOTA
LEGEND
NORTH
ROLETTE
TOWNER
CAVALIER
PEMBINA
WALSH
MARSHALL
GRAND FORKS
POLK
MAHNOMEN
BECKER
CLAY
WILKIN
OTTER TAIL
TRAILL
STEELE
NELSON
GRIGGS
BARNES
RANSOM
SARGENT
RICHLAND
ROBERTS
TRAVERSE
GRANT
STEVENS
BENSON
WELLS
EDDY
SHERIDAN
MINNESOTA
DRAINAGE BASIN
RED RIVER OF THE NORTH
MINNESOTA. NORTH DAKOTA. SOUTH DAKOTA
BROAD CLASSIFICATION OF SOILS
STATE PLANNING BOARD
WPA PROJECT NO. 1754

FIGURE 3

TABLE 1.—*Average relative humidity in percent, Red River Basin* [1]

Station	Moorhead, Minn.			Devils Lake			Grand Forks		Average		
Time	7 a. m.	Noon	7 p. m.	7 a. m.	Noon	7 p. m.	7 a. m.	7 p. m.	7 a. m.	Noon	7 p. m.
Length of record (years)	47	14	47	26	13	26	17	17	30	13.5	30
Years of record	1888–1934	1921–34	1888–1934	1905–30	1918–30	1905–30	1919–35	1919–35			
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
December	89	78	85	89	83	86	87	85	88	81	86
January	88	76	85	89	84	86	85	86	87	80	86
February	88	75	84	89	82	85	85	82	87	79	84
Winter	88	76	85	89	83	86	86	84	88	80	85
March	87	65	79	85	74	77	85	78	86	70	78
April	83	52	61	80	56	59	79	61	81	54	60
May	78	45	52	75	47	50	70	51	74	46	51
Spring	83	54	64	80	59	62	78	63	80	56	63
June	82	52	59	79	54	58	78	59	80	53	59
July	84	50	59	83	51	56	79	59	82	51	58
August	86	47	57	84	46	53	81	55	84	46	55
Summer	84	50	58	82	50	56	79	58	83	50	57
September	87	52	62	84	52	59	84	61	85	52	61
October	85	57	67	84	57	66	85	67	85	57	67
November	88	69	80	86	74	80	87	80	87	72	82
Fall	87	59	70	85	61	68	85	69	86	60	69
Annual	85	60	69	84	63	68	82	69	84	62	69

[1] From records of U. S. Weather Bureau.

NOTE.—Moorhead, Minn., is located just south of the center of the Red River Basin; Grand Forks, N. Dak., is located just north of the center of the basin; and Devils Lake, N. Dak., is located just outside of the basin.

The mean annual temperature for the area, based upon the average of the mean annuals of temperature-recording stations within the area and immediately adjacent thereto is 38.7° Fahrenheit. The seasonal variations in temperatures for Moorhead, Minn., near the center of the basin are shown in table 2.

TABLE 2.—*Monthly average temperature for Moorhead, Minn.*[1]

Month	Average	Month	Average	Month	Average
	°F		°F		°F
January	4.9	May	54.4	September	57.7
February	8.8	June	64.6	October	44.8
March	23.7	July	69.0	November	26.9
April	42.3	August	66.7	December	12.4
				Year	39.7

[1] From records of U. S. Weather Bureau. Period of record, 54 years, 1881–1934.

The winters in the area are long and severe and the summers are comparatively short. The growing season or time between the latest and earliest killing frosts averages between 103 and 139 days for various localities in the basin, the lower value being near the international boundary. Killing frosts have been recorded as late as June and early July, and as early as August, although ordinarily the last killing frost can be expected in the middle part of May and the first in the middle part of September. Although the period between killing frosts is comparatively short the days are long and the percentage of sunshine is high. The average annual sunshine at Moorhead, Minn., is 59 percent.

Winds and Precipitation

The wind is an important factor affecting the precipitation in the Red River Basin. Although the prevailing winds in this region are from the northwest the winds from the southeast bring most of the precipitation. The westerly winds, when they come from the Pacific Ocean, carry a large amount of moisture but they are chilled as they rise to great heights to cross the Rocky Mountains and as a result most of their moisture content is lost on the west slope of the Divide. As the winds descend again to the plains their relative humidity falls as they are warmed and they become drying winds instead of moisture laden winds. On the other hand the winds from the south and east travel up from the Gulf of Mexico without crossing any regions of high elevation. Although they precipitate much of their moisture content on the way, they still drop a considerable amount in the Red River Basin. During the growing season the prevailing winds are from the south and east and as a result a

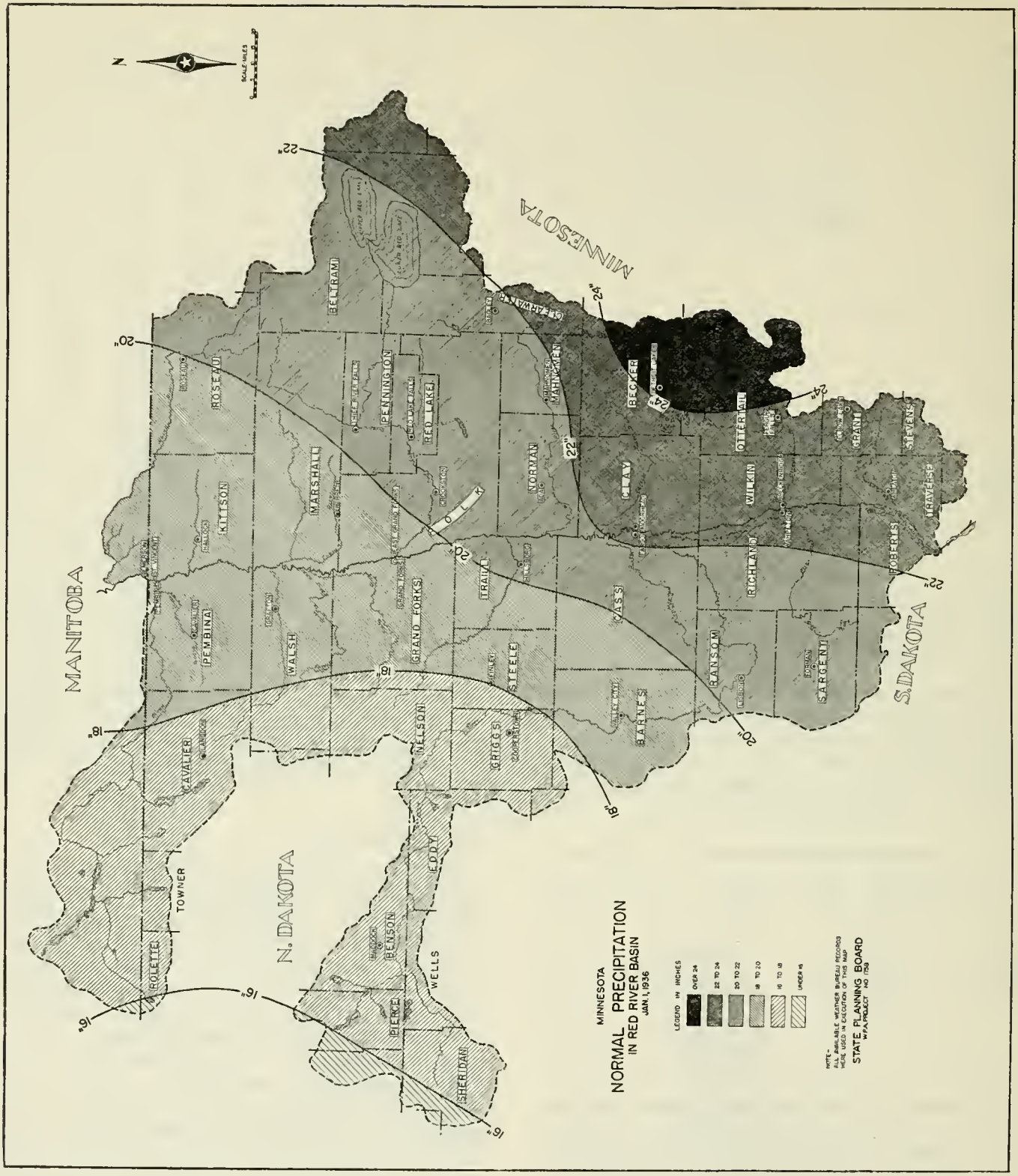

MINNESOTA
MANITOBA
N. DAKOTA
S. DAKOTA
ROSEAU
KITTSON
MARSHALL
BELTRAM
PENNINGTON
RED LAKE
NORMAN
MAHNOMEN
BECKER
CLAY
OTTER TAIL
WILKIN
GRANT
STEVENS
TRAVERSE
ROBERTS
RICHLAND
CASS
TRAILL
GRAND FORKS
WALSH
PEMBINA
STEELE
NELSON
GRIGGS
BARNES
RANSOM
SARGENT
ROLETTE
TOWNER
CAVALIER
PIERCE
BENSON
EDDY
WELLS
SHERIDAN
22"
20"
18"
16"
24"
NORMAL PRECIPITATION
IN RED RIVER BASIN
JAN 1, 1936
LEGEND IN INCHES
OVER 24
22 TO 24
20 TO 22
18 TO 20
16 TO 18
UNDER 16
STATE PLANNING BOARD

FIGURE 4

large proportion of the annual precipitation falls during that period. Table 3 gives the wind directions and velocities for the different months of the year as recorded at Moorhead, Minn.

TABLE 3.—*Wind velocities and directions at Moorhead, Minn.*[1]

Month	Average velocity	Prevailing direction	Highest velocity	Direction of highest velocity
January	0.8	NW.	42	SE.
February	10.0	NW.	49	SE.
March	10.5	N.	47	NW.
April	10.9	N.	43	SE.
May	10.2	N.	49	SE.
June	9.4	SE.	47	S.
July	8.3	S.	58	NW.
August	8.4	SE.	43	S.
September	9.4	S.	43	SW.
October	9.8	NW.	41	SE.
November	9.7	NW.	38	NW.
December	9.6	NW.	44	NW.
Year	9.7	NW.	[2] 58	NW.

[1] From U. S. Department of Agriculture, Weather Bureau—Annual Meteorological Summary with Comparative Data, compiled by R. J. McClurg, 1934. Period of record, 54 years, 1881–1934.

[2] July 1890.

Figure 4 shows the mean annual precipitation throughout the basin. This map has been prepared using all of the available records of precipitation stations. The station records available, the length of record, and the interruptions of record are shown in figure 5. It is recognized that the mean annual values arrived at in this way are unbalanced because of the relatively few stations available prior to 1900, as evidenced by the fact that in 1882 there was one station to about 8,500 square miles while in 1930 there was one to about 910 square miles. The charts are however sufficiently satisfactory to develop a picture of available water as precipitation in different parts of the area. The annual precipitation on the entire area based on the mean of the annual average for all the stations in the basin up to January 1, 1934, is 20.11 inches and the mean annual rainfall varies from about 16 inches to about 24 inches within the basin. If these charts are compared with the tables attached to various subbasin studies some differences will be found because of the use of only a restricted number of stations in determining the values of each subbasin.

Studies of mean annual precipitation bring out clearly the first of the fundamental considerations underlying a water plan for this basin—that is, a very sharply marked difference in mean annual rainfall between the eastern and western sides of the basin. The maximum precipitation occurs over the higher land embraced in the Otter Tail basin and in the headwaters of the Minnesota Wild Rice, the Buffalo, and the Red Lake Rivers. The smallest annual precipitation occurs over the headwaters of the North Dakota streams. This difference is the basic reason for the strong differentiation in the economic conditions of the two sides of the area and it also points clearly to the upper drainage areas of the Minnesota streams as being the only section where further development of water resources may be expected to be found possible in an important way.

To be of the greatest benefit to growing crops, precipitation must come during the growing season when the ground is able to absorb a large percentage of it and the plants can make use of it. These conditions are especially favorable to growing crops in the Red River Valley. About one-half of the total annual precipitation comes in the 3 months most important to the growing crops, May, June, and July, and about three-fourths of it in 6 months from April to September, inclusive. The seasonal variation in precipitation is shown in table 4.

TABLE 4.—*Mean seasonal variation in precipitation* [1]

	Winter, December–February	Spring, March–May	Summer, June–August	Autumn, September–November	Total
Precipitation in inches	1.70	5.09	9.03	4.29	20.11
Percentage of annual precipitation	8.5	25.3	44.8	21.4	100.00

[1] From Inventory of the Water Resources of the Great Lakes, St. Lawrence River, and Red River of the North Drainage Area by L. K. Sherman, regional water consultant. A summary of the average for all recording stations within the basin.

Showers occur most frequently during the growing season. Their average frequency for representative stations within and near the basin for the 20-year period 1915 to 1935, inclusive, is shown in table 5. The average length of time between all types of showers is 3.22 days. The longest dry period during this interval was 34 days recorded April 30 to June 2, 1917, at Devils Lake just outside the basin. The average duration of the longest dry period each year was about 17 days.

TABLE 5.—*Frequency of showers* [1]

Rainfall in inches	Average number per month						Average number of days between showers
	May	June	July	Aug.	Sept.	Total	
0.01 to 0.10 inch	4.48	5.06	3.86	3.68	3.74	20.82	7.33
0.11 to 0.50 inch	3.83	4.25	3.54	2.99	3.28	17.89	8.55
0.51 inch	1.57	2.65	2.30	1.23	1.10	8.85	17.28
All types	9.88	11.96	9.70	7.90	8.12	47.56	3.22

[1] From records of the U. S. Weather Bureau. Period of record, 20 years, 1916–35.

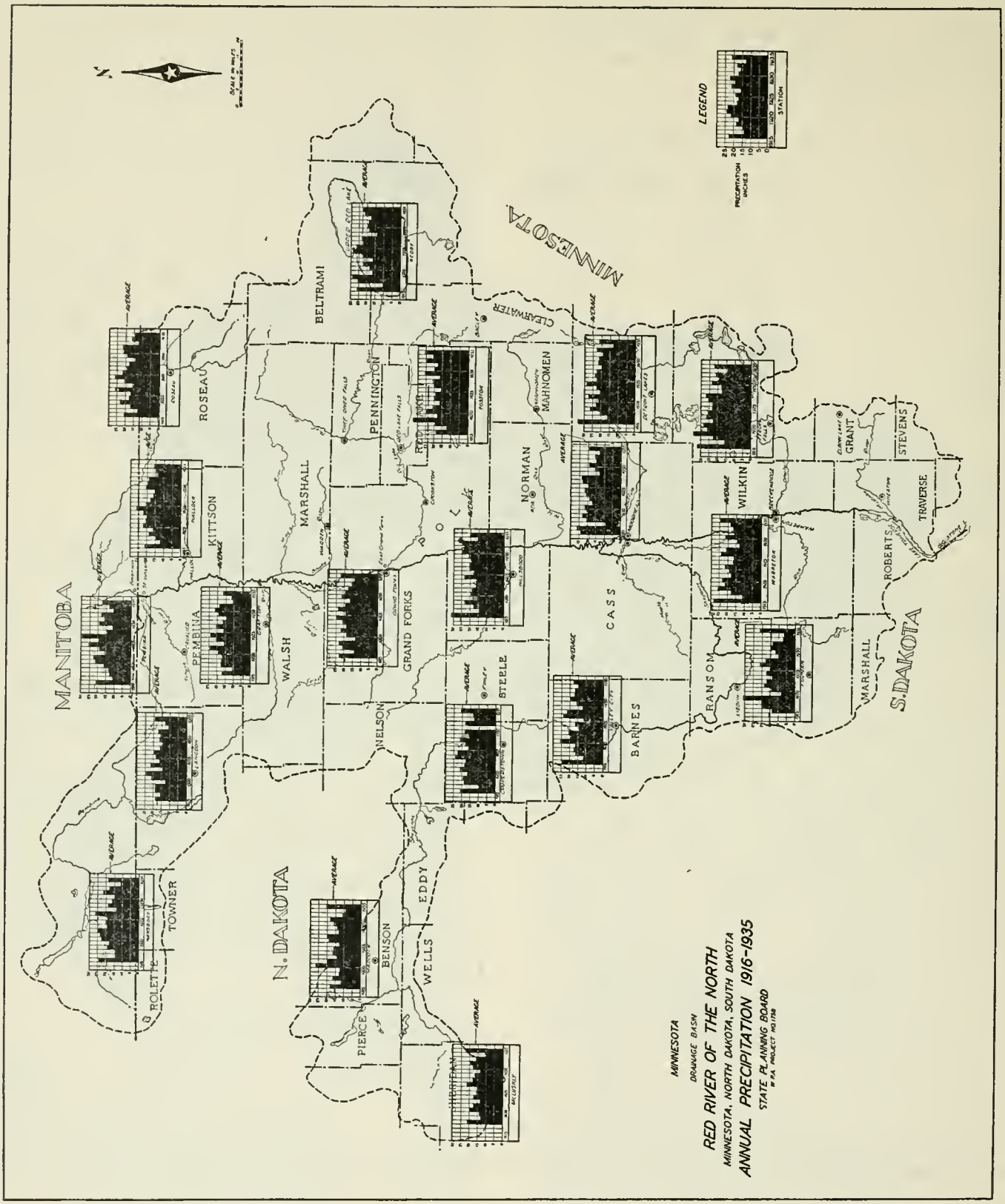

LEGEND
PRECIPITATION INCHES
STATION
MINNESOTA
MANITOBA
N. DAKOTA
S. DAKOTA
ROSEAU
BELTRAMI
CLEARWATER
MAHNOMEN
PENNINGTON
RED LAKE
NORMAN
KITTSON
MARSHALL
PEMBINA
WALSH
GRAND FORKS
POLK
CASS
WILKIN
GRANT
STEVENS
TRAVERSE
ROBERTS
MARSHALL
RANSOM
BARNES
STEELE
NELSON
EDDY
WELLS
BENSON
PIERCE
TOWNER
ROLETTE
MINNESOTA
DRAINAGE BASIN
RED RIVER OF THE NORTH
MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA
ANNUAL PRECIPITATION 1916-1935
STATE PLANNING BOARD
P.W.A. PROJECT NO 178

FIGURE 5

The average mean annual snowfall in the Red River Basin is about 34 inches. The snow seldom reaches this depth, however, because melting and evaporation take place in the course of the season. The seasonal distribution of snowfall in the Red River Basin is shown in table 6.

TABLE 6.—*Monthly average snowfall in inches* [1]

Month	Average	Month	Average	Month	Average
January	6.5	May	0.3	September	0.1
February	5.7	June	0	October	1.6
March	6.0	July	0	November	4.7
April	2.5	August	0	December	6.6

[1] From Inventory of the Water Resources of the Great Lakes, St. Lawrence River and Red River of the North Drainage Area by L. K. Sherman, regional water consultant.

A summary of the monthly averages for all recording stations within the basin.

Records of excessive short time precipitation in the basin are available for but few points, but records for storms of several days duration were compiled and analyzed from the daily precipitation records by P. T. Simons and Forest V. King in Bulletin No. 1017 of the United States Department of Agriculture, and summarized in a table by L. K. Sherman in his Inventory of the Water Resources of the Great Lakes, St. Lawrence River, and Red River of the North Drainage area. This is shown in table 7.

TABLE 7.—*Storm precipitation* [1]

Year	Date	Length of storm period	Total precipitation at center of storm	Location of storm center	Maximum 24-hour precipitation at one observing
		Days			*Inches*
1897	June 27–29	3	4.66	Amenia, N. Dak.	2.35
1897	July 17–22	6	7.42	Wild Rice, N. Dak.	5.86
1899	Aug. 17–20	4	8.18	Leech Lake, Minn.	4.31
1900	Aug. 4–11	8	10.50	Alexandria, Minn.	3.15
1908	Aug. 26–31	6	6.93	Crookston, Minn.	5.85
1909	July 20–22	3	11.10	Beaulieu, Minn.	10.75
1915	June 10–13	4	3.91	Detroit, Minn.	2.75
1915	June 26–28	3	5.04	Mayville, N. Dak.	3.98
1916	Apr. 18–21	4	2.58	Campbell, Minn.	2.26
1916	May 13–16	4	3.34	Fullerton, N. Dak.	2.94
1916	June 28–30	3	3.84	Beardsley, Minn.	3.67
1919	June 20–30	4	6.13	Cando, N. Dak.	5.30
1919	July 1–4	4	9.02	Warroad, Minn.	4.92

[1] From Inventory of the Water Resources of the Great Lakes, St. Lawrence River, and Red River of the North Drainage Area. Data taken from Bulletin No. 1017 of the U. S. Department of Agriculture, 1922 by P. T. Simons and Forest V. King.

The only satisfactory study of the variation in annual precipitation is that published in Geological Survey Water Supply Paper No. 772,[2] and shown diagrammatically on page 64 of that paper. This indicates the extremely wide range of annual value. The years of low precipitation were:

	Inches
1889	15.2
1910	12
1917	13.4
1929	15.5
1934	14.1

The years of high precipitation were:

	Inches
1882	27.4
1892	27.2
1916	27.8

It seems well to anticipate here the unusual importance in the Red River Basin of this wide fluctuation in annual amount. The lower diagram on page 64 of Water Supply Paper No. 772 shows the 10-year progressive average of precipitation minus run-off, which may be taken as the approximate amount of water required for satisfactory transpiration and evaporation. If, for a rough consideration, this is given the value of 20 inches, it is clear that whenever annual rainfall is less than that amount, (*a*) agriculture is seriously affected, and (*b*) the vegetation will take up precipitation in such an amount that low-water stream flow will be reduced to extremely low values. If the average annual precipitation is taken as 22 inches, and the evapo-transpiration demands as 20 inches, it is obvious that under average conditions the remaining surface water susceptible of conservation must be less than the 2 inches difference.

Evaporation

There is but little data available on evaporation from open water surfaces but Prof. E. F. Chandler studied the rate of evaporation from a shallow lake near Grand Forks for a period of 10 years, 1905–14. The results were summarized by P. T. Simons and are shown in table 8. This gives the average value for annual evaporation as 31.63 inches, which agrees very well with other recorded data for portions of the year

TABLE 8.—*Mean monthly temperature and evaporation at University of North Dakota near Grand Forks, N. Dak.*[1]

Month	Mean temperature	Mean evaporation	Month	Mean temperature	Mean evaporation
	°F.	*Inches*		°F.	*Inches*
January	4.0	0.40	August	65.5	4.60
February	7.3	.60	September	57.7	3.63
March	22.8	1.20	October	45.9	2.11
April	44.5	3.22	November	27.6	.63
May	52.1	4.12	December	11.3	.40
June	65.0	4.94			
July	67.5	5.78	Total		31.63

[1] From Inventory of the Water Resources of the Great Lakes, St. Lawrence River, and Red River of the North Drainage Area. Data from P. T. Simons, observations by Prof. E. F. Chandler, professor of civil engineering, University of North Dakota from shallow lake near Grand Forks, N. Dak., during the 10-year period 1905–14.

[2] Studies of Relations of Rainfall and Run-off in the United States, W. G. Hoyt and others, U. S. Government Printing Office, Washington, D. C., 1936.

made by the Weather Bureau at Edgeley, N. Dak. However, the figure generally used for computing the evaporation from water surfaces in this area is 36.38 inches. Computations by Meyer give mean values of about 24 inches for the southern and eastern parts of the basin but extreme values are from 13 to 28 inches.

Run-Off in Basin

The run-off in the Red River Basin varies from one-half inch or less at the headwaters of the Sheyenne River to 3 to 4 inches for the Red Lake and Otter Tail Rivers. The only place in the basin where accurate records have been kept for a long period of time is at Grand Forks, N. Dak., where data go back to 1882. The average annual run-off from the Red River watershed above that point up to 1935 was 1.25 inches. The average before 1924 was 1.40 inches. Up to 1924 the average run-off for the Sheyenne River Basin was 0.54 inch and for the Pembina River Basin was 0.82 inch. At the same time the average for the Red Lake River Basin was 2.83 inches and for the Otter Tail River Basin, 3.55 inches. It is thus apparent that the greater part of the flow of the Red River at Grand Forks comes from its tributaries on the Minnesota side. Prof. E. F. Chandler prepared the data that appear in table 9 showing the relation of the drainage area and the relative amounts of the total flow of the Red River past the international boundary as furnished by the various tributaries.

TABLE 9.—*Average yearly run-off* [1]

River	Recording station	Drainage area, square miles	Annual run-off		Average flow, second-feet	Remarks
			Inches	Acre feet		
Red River	Grand Forks	25,500	1.25	1,700,000	2,350	Complete record.
Do	Fargo	6,420	1.09	375,000	518	Records for 32 years proportioned.
Red Lake River	At mouth, Minn.	5,760	2.50	768,000	1,060	
Pembina River	At mouth, N. Dak.	3,530	.84	158,000	218	Records for 26 years proportioned.
Otter Tail River	At mouth, Minn.	1,840	2.75	268,000	370	Records for 19 years proportioned.
Bois des Sioux	At mouth	1,860	.20	20,000	27	Records for 15 years proportioned.
Wild Rice	At mouth, Minn.	1,440	1.90	145,000	200	Records for 12 years proportioned.
Sheyenne	At mouth, N. Dak.	7,380	.42	164,000	227	Records for 10 years proportioned.
Two Rivers	At mouth, Minn.	1,020	1.90	103,000	143	Records for 9 years proportioned or estimated.
Park River	At mouth, N. Dak.	1,130	.80	48,000	66	Estimates assisted by records for 3 or 2 years very uncertain.
Red River	do	35,500	1.22	2,320,000	3,200	Do.
Forest River	do	1,000	1.00	54,000	74	Do.
Buffalo River	At mouth, Minn.	1,400	1.30	96,000	133	Do.
Tamarac River	do	580	1.50	46,000	64	Estimates, with no records of this stream, but merely adjoining streams.
Snake River	do	1,040	1.50	83,000	115	Do.
Turtle River	At mouth, N. Dak.	700	.80	30,000	41	Do.
Sand Hill	At mouth, Minn.	530	1.00	28,000	39	Do.
Goose River	At mouth, N. Dak.	1,260	.70	47,000	65	Do.
Elm River	do	460	.70	17,000	24	Do.
Wild Rice River	do	2,210	.60	71,000	98	Do.

River	Recording station	Drainage area, square miles	Run-off, inches	As finally used		Remarks
				Area, square miles	Run-off proper, inches	
Red River	Grand Forks	25,500	1.25	25,500	1.25	1882-1934 (52 years).
Do	Fargo	6,420	1.00	6,420	1.09	1902-33 (31 years).
Red Lake River	Crookston	5,320	2.49	5,760	2.50	1902-33 (31 years).
Pembina River	Neche	2,960	.74	3,530	.84	1904-08 (4 years); 1910-15 (5 years); 1919-33 (14 years).
Otter Tail River	Fergus Falls	1,310	3.22	1,840	2.75	1900-16 (16 years); 1931-32 (1 year).
Bois des Sioux		1,460	.11	1,860	.20	1919-33 (14 years).
Wild Rice River	Minnesota	805	1.72	1,440	1.90	1909-17 (8 years); 1931-33 (2 years).
Sheyenne River	West Fargo	5,420	.44	7,380	.42	1902-06 (4 years); 1919, 1930-33 (3 years).
Two Rivers	Hallock, Minn.	776	.81	1,020	1.90	1911-14 (3 years); 1929-33 (4 years).
Red River	International boundary	35,520	.45	35,520	1.22	1930-32 (2 years).
Park River	Grafton	1,010	.04	1,130	.80	1931-33 (2 years).
Forest River	Minto	910	.25	1,000	1.00	1932-33 (1 year).
Buffalo River	Dilworth	1,310	.31	1,400	1.30	Do.

[1] Computed by Dean E. F. Chandler, University of North Dakota for 53 years, 1882-1934, inclusive, from all available records.

The percentage of total flow for the streams given in the table is an estimate based on gaging station records for periods of various lengths on the different streams. Since the run-offs given in this table include those of an excessive number of dry years they probably can be used with safety in computing the average volume of water available for storage on various streams.

From these data and knowledge of the different characteristics of the two sides of the basins, it is quite clear that the conservation possibilities on the North Dakota side are limited, while the resources on the Minnesota side appear to be more richly available for further development.

Long-Time Trends

Figure 18 of Water Supply Paper No. 772 brings out sharply the periodic variation of wet and dry years. These variations or cycles are quite evident even when examined on the basis of 10-year averages. The 10-year averages also indicate an apparent slow increase in mean annual precipitation up to about 1905 or 1909 and a definite downward trend from those years to 1935, with the values for the last 5 years dropping lower than any previous record. Whether this downward trend in annual values is a part of a long-time cycle or whether it is the result of man's activities has been the subject of considerable disagreement among hydrologists. The height of opinion possibly leans toward a composition of the two effects. We are probably justified in assuming that the man-made changes in surface conditions, particularly with regard to drainage and possibly to deforestation, have had some small part in producing the reduced rainfall of recent years and any long-range plan should involve considerations for projects which might have a counter effect.

The following remarks apply to table 9:

System for computing average yearly run-off of streams in Red River Valley, from all available records, as used by E. F. Chandler of University of North Dakota, on this date.

All areas of drainage basins as given in this table are accurate, and were carefully measured in square miles from the best maps (by E. F. Chandler, published 1922).

But if the station was not at the mouth and did not include the entire river, the run-off per square mile was used as recorded for the upper portion of the area, or was slightly modified by E. F. Chandler according to his judgment based upon differences in topography toward the mouth.

The records of run-off at regular stations are entirely from the published records of the United States Geological Survey.

At Grand Forks, N. Dak., on the Red River, the records are complete for 53 years, 1882 to 1934 inclusive. This was used as control for the other stations of shorter records. From the Grand Forks control station it was determined how much the average of that partial period of shorter record was, in percentage, above or below the average of the entire 53-year period. The shorter-period average at each other station was then proportioned down or up by that percentage, so as to give an assumed 53-year average, except that if the record were very short, some modifications were made according to the judgment of E. F. Chandler.

For rivers with no records at all, the run-off figures were merely based on estimates from adjoining streams and topography.

On this basis, with years of record, area, and run-off for each stream as tabulated below, an assumed run-off figure was calculated to be used as coming from the whole 53 years.

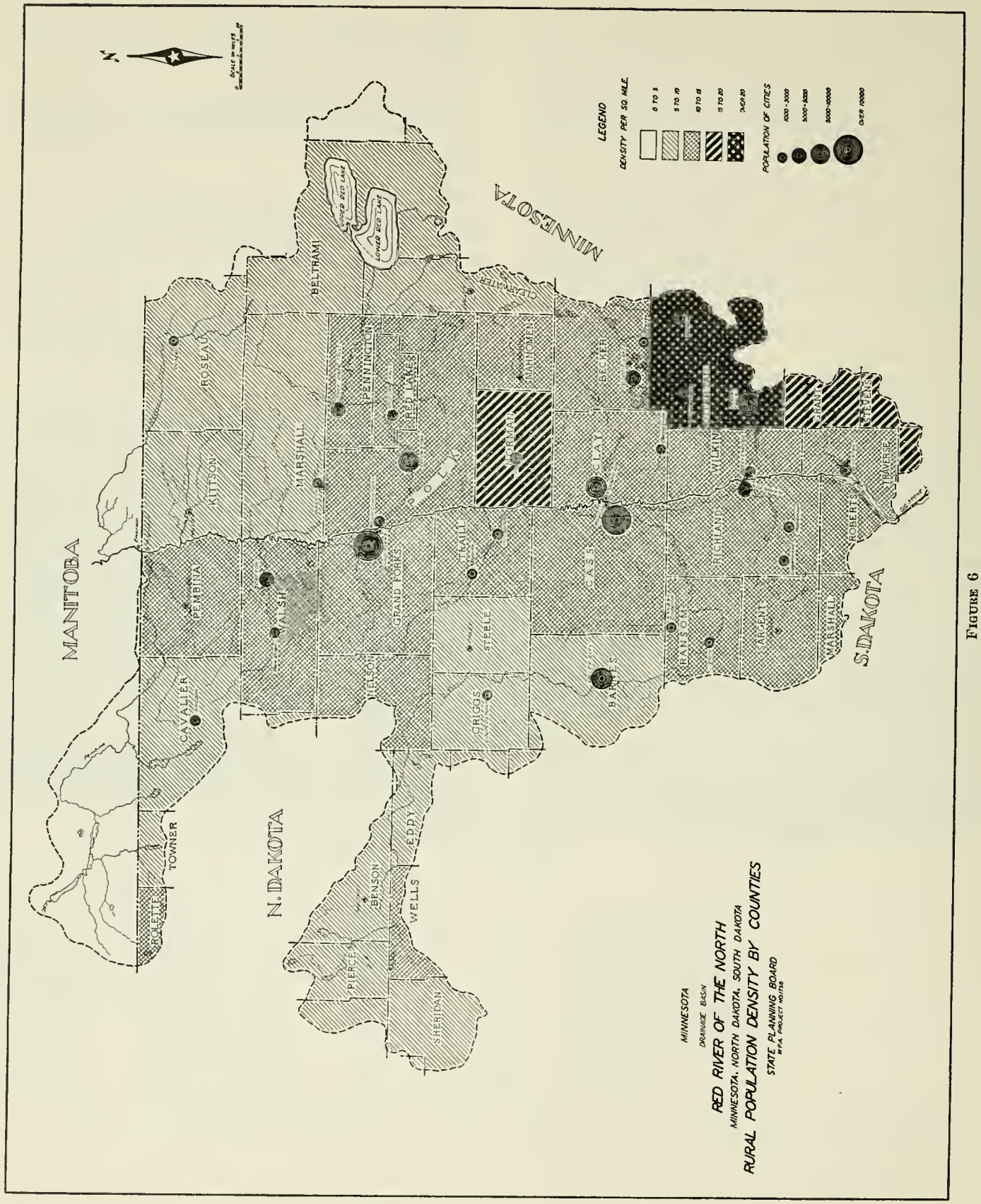

MANITOBA
MINNESOTA
N. DAKOTA
S. DAKOTA
LEGEND
DENSITY PER SQ. MILE
0 TO 5
5 TO 10
10 TO 15
15 TO 20
OVER 20
POPULATION OF CITIES
1000 - 5000
5000 - 10000
OVER 10000
ROLETTE
TOWNER
CAVALIER
PEMBINA
WALSH
KITTSON
ROSEAU
MARSHALL
BELTRAMI
LOWER RED LAKE
PENNINGTON
RED LAKE
CLEARWATER
MAHNOMEN
NORMAN
POLK
GRAND FORKS
TRAILL
STEELE
NELSON
GRIGGS
PIERCE
BENSON
EDDY
WELLS
SHERIDAN
CASS
CLAY
BECKER
BARNES
RICHLAND
WILKIN
TRAVERSE
GRANT
STEVENS
ROBERTS
MARSHALL
RED RIVER OF THE NORTH
MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA
RURAL POPULATION DENSITY BY COUNTIES
STATE PLANNING BOARD

FIGURE 6

STAFF REPORT—SECTION II
ECONOMIC HISTORY, PRESENT STATUS, AND TRENDS

The water requirements in any area are determined primarily by the size of the population and the nature and intensity of industrial developments. It is pertinent, therefore, to inquire into the economic history of the area comprising the Red River of the North drainage system. Consideration of this history may make possible a reasonable forecast of future developments and of future water requirements.

Population

In 1930 the total population of the basin was recorded as 489,091. Of this total approximately 248,000 were in North Dakota, 233,000 in Minnesota, 8,000 in South Dakota.

From 1890 to 1910 the entire basin and each of its principal subdivisions grew rapidly in population. The totals were 228,000 in 1890, and 443,000 in 1910. Since this latter date the growth of population has been much slower until in the decade 1920–30 the increase was only 4,000. The complete data on population, and its changes from 1890–1930 are shown for the area as a whole, and for the sub-basins in table 10.

While the total population had continued to grow in each decade to 1930, the rural population outside incorporated places declined after 1920. Data on this point are given in detail in table 11. It is evident from these data that agriculture reached a high degree of development as early as 1900, at least so far as such developments can be measured by population. These data suggest that the agricultural population of the area is not likely to increase further, unless there is some substantial change in the type of agricultural activity. This point will be referred to again a little later. Rural population densities by counties for the basin are shown in figure 6.

TABLE 10.—*Total population*

State	Subbasin	1890	1900	1910	1920	1930
Minnesota	Bois des Sioux	10,917	17,070	16,896	17,155	18,199
	Buffalo-Wild Rice	39,000	56,070	60,549	70,594	71,677
	Otter Tail	26,085	37,056	40,913	45,182	46,614
	Red Lake	21,304	39,690	52,882	62,640	58,448
	Snake-Roseau	16,631	31,866	36,190	40,497	37,625
Minnesota, total		113,937	181,752	207,430	236,068	232,563
North Dakota	Sheyenne	29,373	57,706	86,279	89,210	88,032
	Wild Rice	13,379	19,854	24,711	25,452	24,989
	Other	70,453	108,890	116,695	125,786	135,486
North Dakota, total		113,205	186,450	227,685	240,448	248,507
South Dakota, total		[1] 950	7,075	7,891	8,688	8,021
Red River Basin, total		228,092	375,277	443,006	485,204	489,091

[1] Estimated.

TABLE 11.—*Rural farm and non-farm population outside incorporated places*

State	Subbasin	1890	1900	1910	1920	1930
Minnesota	Bois des Sioux	9,279	12,977	11,736	12,275	13,011
	Buffalo-Wild Rice	33,526	45,098	43,831	50,333	49,424
	Otter Tail	18,624	23,818	23,005	24,854	24,609
	Red Lake	15,894	26,737	32,971	40,703	37,071
	Snake-Roseau	15,110	27,564	29,081	31,324	28,962
Minnesota, total		92,433	136,194	140,624	159,489	153,077
North Dakota	Sheyenne	25,365	50,140	66,832	66,708	64,702
	Wild Rice	12,922	17,977	19,073	19,351	19,247
	Other	50,787	69,182	63,380	60,828	59,177
North Dakota, total		89,074	137,299	149,285	146,887	143,126
South Dakota, total		[1] 950	6,869	7,304	7,426	6,854
Red River Basin, total		182,457	280,362	297,213	313,802	303,057

[1] Estimated.

Not only has the rural population ceased to increase, but also the population of the incorporated places of less than 2,500 reached an approximate maximum in 1920. Data in support of this point are presented in table 12. When one considers the change in transportation facilities and in the purchasing habits of rural families, the conclusion seems inescapable that the necessity for small service towns is decreasing.

TABLE 12.—*Population of incorporated places (less than 2,500)*

State	Subbasin	1890	1900	1910	1920	1930	Number of villages, 1930
Minnesota	Bois des Sioux	1,638	4,093	5,160	4,880	5,188	12
	Buffalo-Wild Rice	3,386	7,242	11,878	14,541	14,602	33
	Otter Tail	2,435	5,456	8,214	9,321	8,941	14
	Red Lake	967	3,698	6,105	7,937	7,866	21
	Snake-Roseau	1,521	4,302	7,109	9,173	8,663	21
Minnesota, total		9,947	24,791	38,466	45,852	46,260	101
North Dakota	Sheyenne	2,919	5,120	14,841	17,816	18,062	40
	Wild Rice	457	1,877	5,638	6,101	5,742	13
	Other	10,112	24,913	26,506	23,406	24,266	54
North Dakota, total		13,488	31,910	46,985	47,323	48,070	107
South Dakota, total		------	206	587	1,262	1,167	6
Red River Basin, total		23,435	56,907	86,038	94,437	94,497	214

This observation, coupled with the actual population trends just referred to, leads to the conclusion that the population of the small towns and villages in the Red River Basin is not likely to increase in the future.

This calls for consideration of the population resident in incorporated towns, villages, and cities of over 2,500. Data for this group are summarized in table 13. While the rate of population growth has not been

TABLE 13.—*Urban population* [1]

State	Subbasin	1890	1900	1910	1920	1930	Number of centers, 1930
Minnesota	Bois des Sioux	------	------	------	------	------	------
	Buffalo-Wild Rice	2,088	3,730	4,840	5,720	7,651	1
	Otter Tail	5,026	7,782	9,694	11,007	13,064	2
	Red Lake	4,443	9,255	13,806	14,000	13,511	3
	Snake-Roseau	------	------	------	------	------	------
Minnesota, total		11,557	20,767	28,340	30,727	34,226	6
North Dakota	Sheyenne	1,089	2,446	4,606	4,686	5,268	1
	Wild Rice	------	------	------	------	------	------
	Other	9,554	14,795	26,809	41,552	52,043	4
North Dakota, total		10,643	17,241	31,415	46,238	57,311	5
South Dakota, total		------	------	------	------	------	------
Red River Basin, total		22,200	38,008	59,755	76,965	91,537	11

[1] Incorporated places with over 2,500 population.

maintained since 1910 there was, nevertheless, an important increase in the decade ending in 1930. This increase totaled about 15,000 of which 11,000 was in North Dakota. Growth at Fargo and Grand Forks accounted for most of this. Whether further increase in urban population may be expected in this area depends upon the forecast of future industrial development. Attention will be given to this matter a little later.

The population data indicate that rural development has reached at least a temporary maximum. The same may be said of the small service villages and towns. Increase in population continued at a fairly rapid rate in the larger urban communities. Even in these centers the increase in the decade ending in 1930 (18 percent) was only a little more rapid than that for the total population of the United States (16 percent). It was not nearly so rapid as the increase in urban population of the country as a whole (27 percent). Thus the development of urbanism is proceeding less rapidly in this area than in many other parts of the United States.

Agriculture

The drainage basin of the Red River of the North has had its primary development in agriculture. In 1900, 75 percent of the population of the area was classified as rural, that is, was located either on farms or in small unincorporated towns and villages. This percentage has decreased since the turn of the century but still stood at 65 percent in 1920 and 62 percent in 1930.

In 1900, 61 percent of the entire land area of the basin was in farms and of this 72 percent was actually improved for cropping. By 1930, 77 percent of the entire land area was in farms and over 92 percent of this was improved. Thus it appears that agricultural development will not proceed rapidly in the future in the adding of additional crop lands to the present total. This conclusion is reinforced when one recalls that considerable quantities of lands within this basin are taken up by lake shore devoted to recreational purposes, and other considerable portions are swamp, muskeg, and peat lands, not adaptable to agricultural development. Data concerning the acres in farm land are summarized for the area as a whole and for the several States in table 14.

TABLE 14.—*Acres in farmland*

State	1900	1910	1920	1925	1930	1935
Minnesota:						
Improved	3,442,000	3,513,000	4,967,000	5,768,000	6,068,000	6,734,000
Wood	----------	735,000	995,000	330,000	293,000	356,000
Other	1,795,000	1,006,000	910,000	545,000	512,000	621,000
Total	5,234,000	5,254,000	6,872,000	6,643,000	6,873,000	7,711,000
North Dakota:						
Improved	6,238,000	8,193,000	8,470,000	8,741,000	9,204,000	----------
Wood	----------	228,000	257,000	211,000	237,000	----------
Other	1,948,000	1,055,000	1,162,000	563,000	597,000	----------
Total	8,186,000	9,476,000	9,889,000	9,515,000	10,038,000	----------
South Dakota:						
Improved	----------	----------	----------	----------	423,000	----------
Wood	----------	----------	----------	----------	3,000	----------
Other	----------	----------	----------	----------	25,000	----------
Total	----------	----------	----------	----------	451,000	----------
Red River Basin:						
Improved	9,680,000	11,706,000	13,437,000	14,509,000	15,695,000	6,734,000
Wood	----------	963,000	1,252,000	541,000	533,000	356,000
Other	3,743,000	2,061,000	2,072,000	1,108,000	1,134,000	621,000
Total	[1]13,423,000	[1]14,730,000	[1]16,761,000	[1]16,158,000	17,362,000	[2]7,711,000

[1] Minnesota and North Dakota only.
[2] Minnesota only.

The value of agricultural products for the 3 census years 1910, 1920, and 1930, is summarized in table 15. These data have all the shortcomings of price information whenever the attempt is made to compare years during a period of changing price levels. The attempt may be made, therefore, to adjust the figures for the change in prices of each of the major types of agricultural products. The adjusted value figures are given in table 16.

Attention will be called to the several items in this table.

1. Field crops are by far the largest part of the total value of agricultural products. While the percentage has decreased somewhat it still stood at approximately 80 percent in 1930.

TABLE 15.—*Value of agricultural products in dollars*

State	Products	1910	1920	1930
Minnesota	Dairy	$3,460,000	$9,368,000	$13,994,000
	Field crops	32,561,000	96,432,000	43,566,000
	Forest			1,568,000
	Poultry and eggs	1,448,000	2,986,000	7,092,000
Total		37,469,000	108,786,000	66,220,000
North Dakota	Dairy	1,992,000	6,132,000	8,367,000
	Field crops	77,397,000	142,472,000	62,174,000
	Forest			251,000
	Poultry	1,591,000	3,264,000	3,733,000
Total		80,980,000	151,868,000	74,525,000
Red River Basin, total[1]	Dairy	5,452,000	15,500,000	22,361,000
	Field crops	109,958,000	238,904,000	105,740,000
	Forest			1,819,000
	Poultry and eggs	3,039,000	6,250,000	10,825,000
Total[1]		118,449,000	260,654,000	140,745,000

[1] Does not include South Dakota portion.

TABLE 16.—*Value of agricultural products in millions of dollars adjusted to the 1909–14 price level*

Year	Dairy products[1]	Field crops[2]	Poultry products
1910	5.4	105.0	3.0
1920	8.4	103.0	2.8
1930	18.2	105.0	8.6

[1] The pounds of cream sold as butterfat in the area increased from 7,766,000 pounds in 1910 to 51,700,000 pounds in 1930.

[2] The bushels of wheat produced in the area decreased from 99,000,000 in 1910 to 52,000,000 in 1920. Other field crops decreased correspondingly.

2. There has been no appreciable change in the adjusted value of field crops produced in the area during the past 20 years, which suggests that this part of the agricultural program of the region has reached a point of stability.

3. The production of dairy and poultry products underwent striking percentage increases in the decade ending in 1930. This suggests an intensification of agriculture which might result in smaller farms and more people engaged in agriculture. It might be noted, however, that the average size of farms during the decade stood at approximately 330 acres in each of the last 2 census years. In 1910 the corresponding average was 335 acres. Perhaps, therefore, it will be necessary for the intensification and diversification to be carried much farther before any effect on rural population is felt.

There has been an increase in farm tenancy in the area during recent years. The 1930 census showed approximately 39 percent of all farms operated by tenants. This is almost exactly the figure given for the United States as a whole. Ten years earlier the percentage in the Red River Basin was only 31 percent, which was distinctly lower than the national figure of 38 percent. The recent increase in tenancy in the Red River Basin is occasioned, perhaps, by the particularly adverse conditions that prevailed during the twenties. It is impossible to predict the future trend in this connection especially since the present situation is so similar to that of the country as a whole.

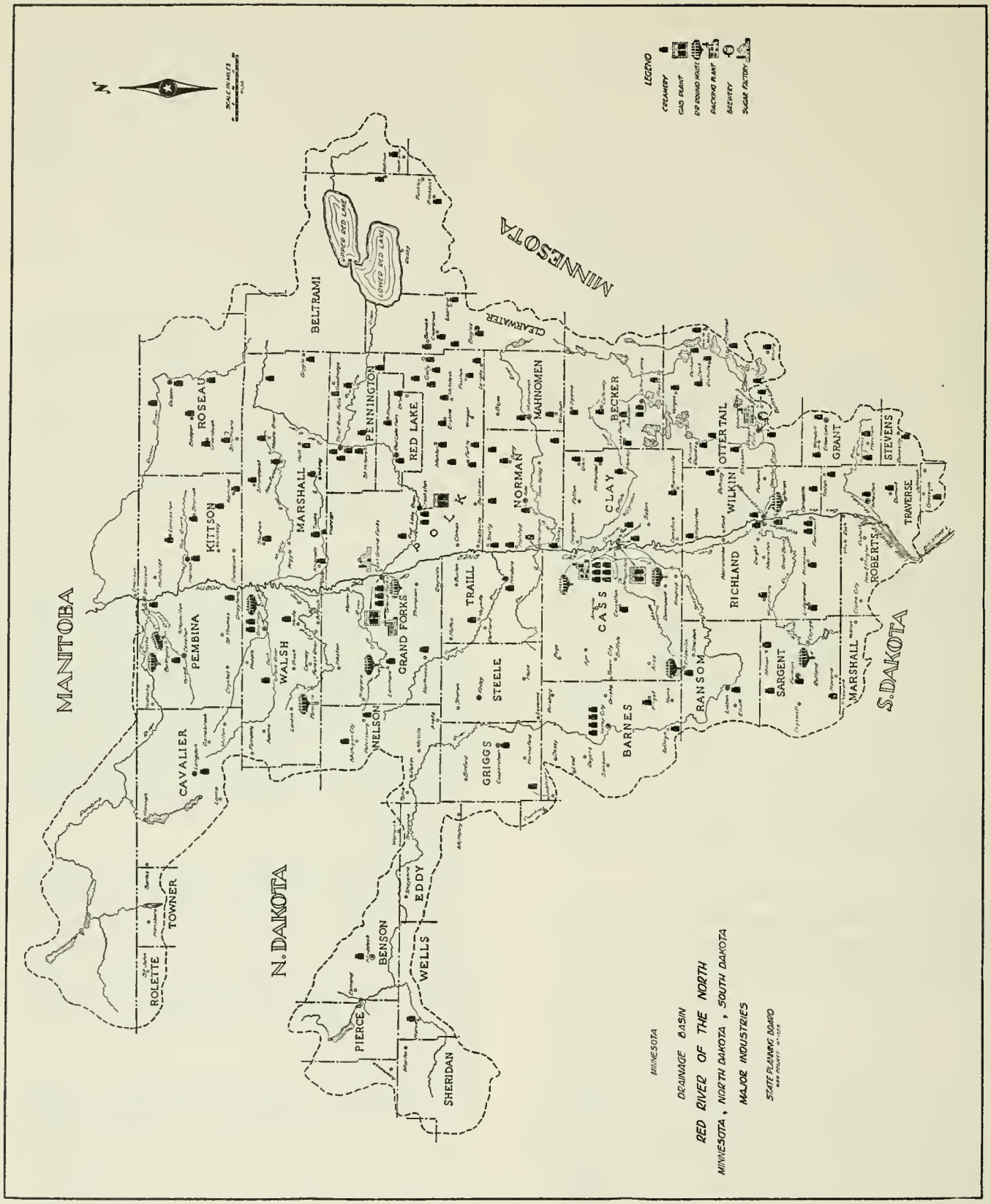
In summary it might be suggested that the history of agricultural development in this area suggests that there will be little change in population concerned directly with agricultural production. On the other hand, there may be an increase in the number of people employed in the processing industries, if the tendency toward dairy and poultry production continues. The effect of such change both on population and on water requirements will be considered in the section on industry.

Industry

The basin of the Red River is industrialized only to a very limited extent. The industries which do exist are the result of two principal situations, namely, first the necessity for processing locally produced agricultural crops, and second, the necessity for certain service industries required wherever there is an established population. The most important industry in the first group in this area is the creameries serving the growing dairy industry. There are 150 creameries located in the basin, the total value of creamery products being $21,694,029 in 1930.

In addition to creameries, there are one beet sugar factory, one large and several small flour mills, and a few minor processing plants. In the second group of industries mentioned above, there are included such miscellaneous concerns as bakeries, machine shops, garages, printing plants, and other small concerns. Nowhere in the area is there any important industrial plant manufacturing for interregional trade, with the exception of the agriculture processing concerns already referred to.

When consideration is given to the natural supplies of raw material, to possibilities of developing power, and to the industrial personnel available for manufacturing enterprises, it does not appear likely that any rapid or unusual development of industry will take place during the next few decades. It is possible, however, that the agriculture processing industries may continue to increase in importance. If this occurs there would result an increase in the number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LOWER RED LAKE
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CLEARWATER
MAHNOMEN
NORMAN
BECKER
CLAY
OTTER TAIL
WILKIN
GRANT
STEVENS
TRAVERSE
GRAND FORKS
TRAILL
STEELE
NELSON
GRIGGS
CASS
RICHLAND
ROBERTS
RANSOM
BARNES
SARGENT
MARSHALL
EDDY
WELLS
BENSON
PIERCE
SHERIDAN
LEGEND
CREAMERY
GAS PLANT
FLOUR MILL
PACKING PLANT
BREWERY
SUGAR FACTORY
MINNESOTA
DRAINAGE BASIN
RED RIVER OF THE NORTH
MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA
MAJOR INDUSTRIES
STATE PLANNING BOARD

FIGURE 7

of creameries, the establishment of one or more beet sugar factories, and additional packing plants for the handling of poultry and other livestock produced in the region. Any such development will increase somewhat the urban population of the area.

In 1930 the percentage of the Minnesota population gainfully employed in all activities combined was approximately 38 percent. Approximately one-fifth of these were engaged in the manufacturing and mechanical industries. The percentage of the people gainfully employed in the counties in the Red River Basin was slightly lower than for the State as a whole, the average in the basin being 36 percent. Of these only about one-tenth were engaged in the manufacturing and mechanical industries. In other words, the proportion engaged in these industries was slightly less than one-half as great in the Red River Basin as in the entire State. It was only one-fourth as great as in Hennepin County, Minn. It may be pointed out, further, that only about 5 percent of the value added by manufacture in Minnesota as a whole is produced in plants lying within the Red River Basin.

There is little reason to expect marked increase in the requirements either for the working population, or for the use of water, arising out of increased industrialization of the area, except as there is further shifting in agricultural production toward the animal industries with the accompanying increase in the processing of animal products.

Trade

The average per capita retail sales in the Red River Basin were lower according to the 1929 census than the average for Minnesota. They were very much lower than for the counties immediately surrounding the Twin Cities. The average was approximately $315 per capita for the counties in the Red River Basin in contrast to $434 in the Twin Cities area. This appears to be typical of agricultural communities in which a considerable proportion of the consumptive needs of the inhabitants is produced for direct family consumption. It should not be taken as implying that the standard of living in such a community is necessarily lowered. For the United States as a whole the per capita retail sales in 1929 were $400. In Minnesota the average for the State was $410, and in North Dakota, $345.

The wholesale trade in this area is confined to a few cities, of which the most important is Fargo. The total wholesale trade of the basin was approximately 65 million dollars in 1929, 43 million of which originated in Fargo. There is no one best way of indicating the relative importance of wholesale trade in an area. Perhaps two indications will be useful, however. The first of these is the ratio of wholesale to retail sales and the second is the per capita volume of wholesale sales. For the United States as a whole there was 1.4 times as much wholesale business transacted in 1929 as there was retail trade. The average per capita volume amounted to $570. In contrast to these figures the ratio of wholesale to retail sales in Minnesota is 1.6 and in North Dakota 1.1 while the per capita wholesale trade in these two States was $660, and $385, respectively.

With these general regional figures as a basis of comparison we may consider the wholesale trade originating in certain representative cities. Data for such comparison are summarized in table 17.

TABLE 17.—*Wholesale trade data*

	Wholesale-retail ratio	Per capita wholesale trade
Fargo (in the Red River Basin)	2.0	$1,500
Twin Cities	2.3	1,475
Chicago	2.7	1,750
St Louis	3.0	1,750
Denver	2.4	1,375
United States total	1.4	570

From these data it appears that there is in the Red River Basin at least one wholesale center that is comparable to leading trade centers elsewhere in its service to the surrounding territory. Since Fargo has developed so far in its wholesale activities it is unlikely that there will be further growth in this line unless or until the general population in the surrounding trade territory increases. In this connection it might be pointed out that the entire population of the Red River Basin was less than one-half million in 1930. The total population of the two States of North Dakota and South Dakota was under 1,400,000. Development of wholesaling in Grand Forks, Valley City, Crookston, Fergus Falls, and Moorhead seems also to have been carried about as far as it is likely to go unless there is substantial increase in the surrounding population. Data on this matter are summarized in table 18.

It might be said that the drainage area contains under 200 wholesale establishments employing about two thousand persons. This number of institutions and employees is probably adequate to take care of the wholesale requirements of the area with little or no expansion.

Recreation

The Red River Basin is largely a flat alluvial plain to the west of which lies a long expanse of prairie, which extends to the foothills of the Rocky Mountain region. Throughout much of the territory west of the Red River there is little relief from monotony of the prairie either in the form of mountainous territory or

of lakes and rivers. In contrast, the major portion of the Otter Tail Basin is thickly dotted with lakes. This area together with the Red Lakes and their immediate environment includes some of the finest wildlife and recreational facilities of the entire country.

Considerable advantage has already been taken of the natural facilities for recreation and vacation in the Otter Tail Basin. This is indicated by the number of summer resorts and tourist camps that are found in the area. There seems to be no question but that the tourist trade in the Detroit Lakes district, for example, will continue to increase until it becomes one of the most important elements in the local income of the entire region. Tourists are attracted into this area not only from the comparatively waterless territory lying to the west, but also from the lakeless region to the south. Many hundreds of tourists come annually from Iowa, Missouri, Kansas, and Nebraska. It is difficult to forecast the water requirements that will result from the tourist trade. It may safely be said, however, that the maintenance of lake levels is absolutely necessary to the continuance of this trade. It is equally essential, of course, that adequate provision be made for the maintenance of safe water supplies for domestic use throughout the vacation territory, and that adequate provision be made for sewage disposal and other sanitary arrangements.

Water Requirements

The water requirements in any area must be considered both in terms of quality and quantity. The matter of quality includes the original chemical composition of the water and its freedom from organic and bacteriological impurities. Throughout most of the Red River Basin the chemical composition of the water is reasonably satisfactory although there are some areas in which the fluoride content presents a real problem. This matter will be discussed further in the section on Water Resources. The matter of organic impurities, on the other hand, is largely the result of man's handling of the watershed. Stream and lake pollution result from improper handling or inadequate treatment of domestic, industrial, and agricultural wastes.

Prevention of pollution can be effected when adequate engineering facilities have been provided, and when adequate stream flow can be maintained in the Red River Basin. The natural stream channels are used to a considerable extent for the transporting of city waste material. This practice makes essential the maintenance of a considerable flow, even at the time of normal low water.

With one exception the major cities and towns of the area use surface water supplies for their domestic systems and discharge their sewage into the river channels. The adequacy and safety of these water supplies are dependent, therefore, on continuous stream flow in sustained volume.

Agricultural Requirements

None of the agriculture in the Red River Basin is under irrigation. In the northern and western portion of the basin, however, the rainfall is little more than that required for annual crop production without irrigation. In the years of light rainfall the total precipitation is undoubtedly less than that required for satisfactory crop production. It will be recalled that in 1930 approximately 70 percent of the entire land area was in crop. In the northern and west part of the basin where the rainfall is the lightest the percentage of land actually in crop is the highest, as there is almost no rotation due to irregular topography. Consequently, it is imperative that precipitation be carefully conserved if the present agricultural production is to be maintained successfully.

Conservation of water for agricultural purposes in this area will require particular attention to the reduction of surface run-off during and immediately following the periods of high precipitation. It may be pointed out in passing that there is a close economic relationship between this problem of reduction of run-off, and the prevention of soil erosion. Whatever is done to check run-off will have the accompanying effect of reduced erosion.

Reduction of run-off involves work at the headwaters so that accumulation of surface water may be kept small. Crop rotation and soil handling are of major importance in this connection.

As water accumulates in the tributary streams and flows into or toward the principal lakes it is desirable to have considerable flexibility in the storage capacity in order to prevent the extreme rise and fall in the main streams below these storage lakes. Not a great deal is known about the movements of water from the lakes into the subsoil where it aids in maintaining well levels and subsurface moisture. There is considerable likelihood, however, that the maintenance of lake levels has a favorable effect on the maintenance of groundwater levels. This is of particular importance throughout much of the Red River Basin, because of the dependence of the individual farmer and of small communities on well water for all domestic purposes.

Urban Requirements

As has already been pointed out the population density of the Red River Basin is light and the urban development is comparatively minor. One hundred and ninety thousand out of the total population of 490,000 live in towns, villages, and cities. Domestic and industrial requirements of this so-called urban

population would be equal to only 0.015 of an inch of rainfall over the entire basin area. That is to say, this small amount out of the total precipitation actually delivered into the water system of the urban communities would take care of their entire requirements. This is less than 0.001 of the total precipitation and it may seem, therefore, to be an unimportant amount. It is certainly to be emphasized that by far the major use of water in this watershed is in the production of crops. The importance of the urban uses lies not in its quantity but in the requirements that it must be delivered continuously in certain quantities at certain points with a certain high degree of purity. These requirements dictate the necessity of flexibility in the system of storage and transportation of water. Since it is true that the demands of agricultural crops and native vegetation are sufficient to use much of the precipitation in normal years, and more than the total precipitation in dry years, it is essential that great care be given to provisions of adequate water for the urban purposes, even though the total urban requirements seem comparatively small.

Nearly all of the urban communities in the basin use surface water supplies. The city of Fargo requires approximately 5.2 cubic feet per second of continuous flow for the use of the city. In addition, it is necessary that a continuous flow be maintained below the city both as a carriage for the industrial wastes and for the supply for the communities farther down the river. Of course, the Red Lake River supplies part of this latter demand but it should be adequately supplemented by continuous flow in the Red River itself.

It may be pointed out further that as urban population increases in the basin with corresponding increase in urban water requirements, there will be no accompanying reduction in rural requirements. Consequently it will become increasingly important that water supplies and transporting systems be maintained both with respect to adequacy and to flexibility.

The waters in the Red River Basin have never been used to any great extent for the development of electric power. The few plants that have been installed have been used mainly as supplementary to steam plants. If the flow in the streams could be more nearly regularized the use of hydro plants would doubtless be extended. This applies especially to the plants on the Otter Tail and Red Lake Rivers.

TABLE 18.—*Wholesale trade*[1] *in cities of over 5,000 population*

State	City	Number of establishments	Total number of employees	Salaries and wages	Total expenses	Inventory (end of year)	Net sales
Minnesota	Crookston	16	97	$153,905	$320,966	$213,083	$2,759,701
	Fergus Falls	12	42	56,529	100,710	111,444	1,322,494
	Moorhead	20	127	189,707	360,011	349,291	3,802,010
Minnesota, total		48	266	400,141	781,687	673,818	7,884,208
North Dakota	Fargo:						
	Wholesalers only	48	588	984,434	2,069,673	1,749,779	13,329,182
	All other types	40	603	1,182,289	2,466,981	2,003,394	29,543,488
	Fargo total	88	1,191	2,166,723	4,536,654	3,753,173	42,872,670
	Grand Forks	29	421	697,897	1,652,847	1,251,532	12,227,727
	Valley City	12	56	89,525	191,623	178,838	1,596,630
North Dakota, total		129	1,668	2,954,145	6,381,124	5,183,543	56,697,027
Total, Red River Basin		177	1,934	3,354,286	7,162,811	5,857,361	64,581,235

[1] From Fifteenth Census of the United States—Wholesale Distribution—1929.

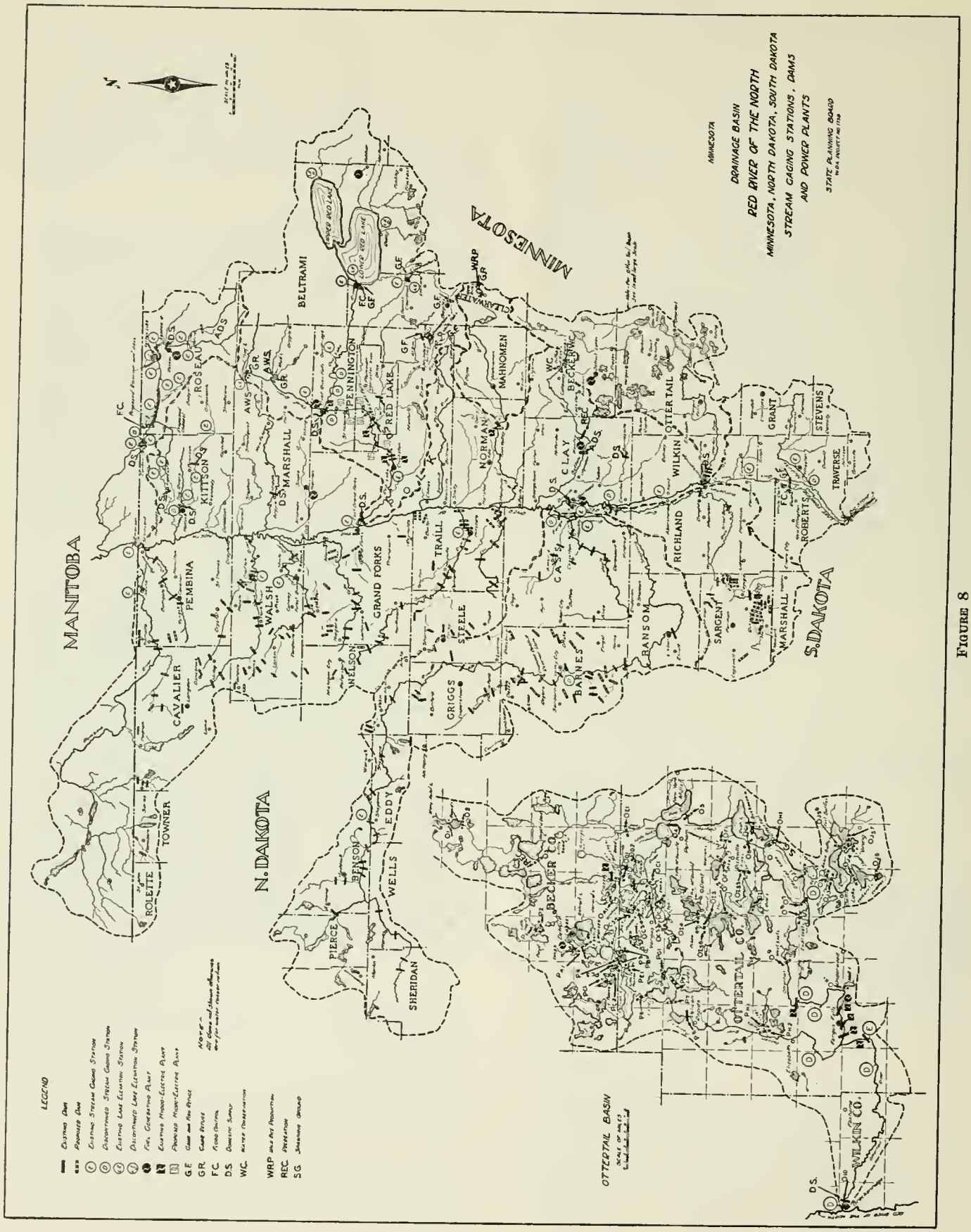

DRAINAGE BASIN
RED RIVER OF THE NORTH
MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA
STREAM GAGING STATIONS, DAMS
AND POWER PLANTS
STATE PLANNING BOARD
MANITOBA
MINNESOTA
N. DAKOTA
S. DAKOTA
BELTRAMI
MAHNOMEN
BECKER
CLAY
WILKIN
OTTER TAIL
GRANT
STEVENS
TRAVERSE
ROBERTS
MARSHALL
ROSEAU
KITTSON
PENNINGTON
RED LAKE
NORMAN
PEMBINA
CAVALIER
ROLETTE
TOWNER
WALSH
MARSHALL
GRAND FORKS
TRAILL
STEELE
GRIGGS
NELSON
RICHLAND
SARGENT
RANSOM
BARNES
PIERCE
BENSON
EDDY
WELLS
SHERIDAN
OTTERTAIL CO.
BECKER CO.
WILKIN CO.
OTTERTAIL BASIN
LEGEND

FIGURE 8

STAFF REPORT—SECTION III
WATER PROBLEMS AND WATER PLAN

History of the Water Problems

During the early years of the development of the Red River Valley a very great portion of the basin was in marsh land. The flow of the streams was subject to good natural regulation. The stream channels were apparently more adequate than at present and water transportation was possible throughout a large part of the year. The Red River was navigable for steamers and boats of possibly a hundred feet in length. These boats operated somewhat regularly on the Red Lake River to and into Red Lake itself. Ground-water levels apparently must have been high. Between 1880 and 1900 the greater part of the valley was put under cultivation and the run-off characteristics were appreciably modified. Between 1900 and 1916 land drainage was installed for a larger part of the natural marsh area and for a great deal of the good cultivated land. It seems probable that soil erosion began in the early years of cultivation and the channels of most of the streams have undoubtedly been decreased in capacity.

The record indicates that serious floods occurred in the earlier years of the occupation, but undoubtedly the important floods of 1913, 1916, and 1919 were aggravated by the man-made changes which had taken place, particularly by the extensive land drainage which was then relatively new and probably in effective operating condition.

In general, changes in land use and in the streams themselves have brought about an increased run-off during the spring break-up and a reduction in the amount of moisture going into ground water. This in turn has resulted in decreased summer stream flow and lowered ground-water levels.

The important cities of the valley have been built up along the Red River, the Otter Tail River, and the Red Lake River. As they have increased in size, they have found ground-water resources inadequate for municipal supplies and with one exception have turned wholly or in part to impounded stream flow for this purpose. Without exception these cities have discharged their sewage untreated into the streams. The improvement of agriculture brought processing industries and these in turn required more of the available water supply and added polluted waters to the rivers.

Within the past 10 years the coincidence of increased demand for water, increased return of polluted water to the stream, and reduced summer stream flow, reached a critical point where the available water in the stream was not equal to the aggregate of the demands and began to be subjected to reuse from city to city down the valley.

Between 1912 and 1920, when the population of the cities was rapidly increasing, precipitation in this area was going through a wet cycle. Serious floods occurred in 3 years and summer stream flow was fairly well sustained. In 1920, drouth-producing conditions began to appear with precipitation at subnormal values in parts of the basin and with an excess of evaporation and transpiration losses. With only slight improvement in 1 or 2 years, this condition persisted until the actual beginning of the serious drouth about 1930. Throughout this whole period there was a downward trend in the available water and an increasingly serious condition as to the quality of water in the streams for urban use. The cities improved their water treatment and certain of them undertook treatment of sewage and other wastes but the stream flow throughout several months of the year was so inadequate for the dilution of wastes that the water was unsatisfactory for city supplies and the streams themselves became odorous and highly objectionable. The situation had become so critical that in 1931 the States of Minnesota and North Dakota agreed to undertake a pollution survey of the river. As the result of this study further treatment of sewage was undertaken by some of the towns, but it became obvious that satisfactory urban supplies and a reasonable condition of the stream itself could not be secured with the water reused to such an extent.

The continuation of the drouth further reduced low-water stream flow in succeeding years to a point where for long periods use of water had to be restricted in some of the cities and only through the most rigidly prosecuted emergency measures was sufficient water made available for ordinary household use. This critical condition occurred in 1933, 1934, and again in 1936. The unanimous opinion that a permanent solution of the water supply and sanitary problems of the valley must be found together with the then current program of the Federal Government with regard to public works, resulted in the organization of the interstate committee.

The committee's studies, while concentrated on the two critical needs described above, took cognizance of the other water problems that existed. These included the widespread inadequacy of the water supplies of the smaller towns heretofore dependent upon ground water and the unsatisfactory quality of much of the ground water, both because of high general mineral

content and because of the presence of fluorides in a damaging amount.

While the area has not been subjected to serious floods during the dry cycle, the experiences of the 1910 to 1920 period clearly indicated that provision must be made for correction of flood-flow conditions before the valley experienced a recurrence of years of high precipitation and of intense storms.

The southeastern part of the area, in particular the Otter Tail Basin, is intensively used for recreation. Its "thousand" lakes are its greatest asset. Their recession, during the drouth period, seriously impaired their use. An important problem existed with regard to the stabilization of lake levels, insofar as could be accomplished.

Agricultural drainage facilities for the fertile lands had been neglected and provision for their rehabilitation was needed.

The widespread drainage of unfertile lands, particularly the peat marshes, had in part been responsible for the unsatisfactory stream-flow characteristics. The restoration of these marshes is important to the main problem and will be valuable for the conservation of wildlife.

Each of these problems is considered in the subsequent sections of the report, and their best solutions are coordinated into the best over-all water plan for the valley as a whole.

Previous Studies and Reports

The most complete report ever prepared, covering the hydrology of this basin, is that on Drainage and Prevention of Overflow of the Valley of the Red River of the North, by P. T. Simons and F. V. King, published as Bulletin No. 1017 of the United States Department of Agriculture dated March 31, 1922. This report summarizes in a very thorough manner available precipitation and stream-flow data up to and including the year 1919. It deals primarily with flood prevention in the valley of the Red River and of the Bois des Sioux, and with the drainage and reclamation of the marsh lands north of Lake Traverse.

There is also available a report of the Minnesota Department of Conservation on the Red Lake River with the accompanying report of Adolph Meyer, consulting engineer, dealing primarily with flood correction in this subbasin.

There have also been reports of the Minnesota Conservation Commission and the State engineer of North Dakota on specific water projects studied by them, a report on Water Supply and Sewage Disposal Conditions, James and Sheyenne River Basins, by the United States Corps of Engineers, July 1935, and also surveys and reports on certain projects carried under the Federal Emergency Relief Administration. The interstate survey and report on stream pollution has been referred to previously.

Organization of the Work of the Committee

The committee, at its first meeting, determined that it would be necessary to divide the drainage area into its principal subbasins and to make an intensive study of each. These studies have resulted in reports by the respective State planning boards on each of these subbasins appended hereto. They contain detailed review of physical conditions, of land use, population trends, and conclusions as to the future economic condition of the area and of the water problems needing solution to permit the best probable type of development to take place.

The findings contained in the subbasin reports have become the basis of analysis of the future development of the valley as a whole, and the solution of the water problems indicated by the subbasin studies have been coordinated into a unified long range water plan for the Red River of the North.

During the course of these studies it has been necessary to make a new analysis of hydrologic factors taking into account basic data accumulated subsequent to the Simons-King studies. This work has been carried out primarily by the staffs of the planning boards with the cooperative assistance and guidance of those officials concerned with water development in all three States. An application of the information to certain of the problems developed complexities requiring more intricate hydrologic study. In this matter the committee secured, through the National Resources Committee, the assistance of Mr. Adolph Meyer as an additional consulting engineer. His report, covering an analysis of the hydrologic features of certain projects is attached hereto as appendix A. In addition to the cooperation by the State offices, a number of the city engineers, water commissioners, and other officials of the principal cities met with the committee on several occasions and furnished valuable information. Dean E. F. Chandler, University of North Dakota, voluntarily contributed important information with regard to stream flow and other water matters. The findings of the committee are discussed in the succeeding topics, each topic dealing with one of the important water uses or water improvement needs.

1. Improvement of Dependable Low Water Stream Flow

The average run-off of the whole basin is 1.25 inches; about two-thirds of this occurs in March, April, May, and June and stream flow throughout the remaining 8 months is extremely small. Since 1930, the monthly run-off during these 8 months has averaged less than one-hundredth of an inch, and the flow

has ceased for relatively long periods. With one exception the larger cities are dependent on stream flow for urban water supply and for the dilution of wastes. During the past 5 years the stream flow has been largely sewage, the water being reused several times before reaching the lower cities of the valley. Sewage and waste pollution have been little improved by stream flow and, in some reaches, the water quality has been further reduced by the growth of organisms attracted by pollutional matter. The raw water available to the municipal water treatment plants of this area is probably the most unsatisfactory supply in any part of the United States. For several years the situation has been critical as to water quality.

With the exception of Moorhead, all the larger cities of the Red River Valley take their water supply from streams and discharge sewage into them. Even in years of mean rainfall the stream flow is insufficient to meet the demands for those uses within the limits of modern sanitary standards. In dry years the flow of the stream at some water supply intakes consists largely of sewage incompletely purified for this purpose by either natural or artificial processes. Any long range plan of water development must be centered on the correction of this condition.

Modification of the quality of low-water stream flow ultimately would require:

(*a*) The reduction of pollutional discharge into the stream to the greatest extent economically practicable.

(*b*) The regulation of stream flow in such manner that the mean dry weather flow will be adjusted to the remaining pollution in accordance with accepted standards of sanitation.

The first requirement must be met by complete treatment of all sewage and industrial wastes and by improvement in rural sanitation. The second indicates the necessity for water conservation by storage and for regulated release to stream flow. There must be improved and maintained low-water channels for the efficient transportation of water from storage sites to the cities on the river.

With the assistance of data furnished by the sanitary authorities of the States and with the consulting advice of Mr. Whittaker, State sanitary engineer of Minnesota, estimates have been prepared of the oxygen demand of treated sewage effluents from the cities, and of treated industrial wastes—appendix B. From pollutions to be anticipated, on the basis of treatment effective to the extent of eighty-five percent, the quantitative values of stream flow are presented which will create a satisfactory oxygen balance. These values are given in table 19 for two conditions: (a) for summer and fall flows when the streams are open to natural reaeration and (b) when the stream is ice-covered, applicable to the months of December to March.

TABLE 19.—*Minimum rates of stream flow*

Location	Summer and fall conditions	Winter conditions
	Cu. ft. per sec.	*Cu. ft. per sec.*
Below Fergus Falls	25	25
Below Breckenridge and Wahpeton	25	40
Below Fargo and Moorhead	60	145
Below Sheyenne River	200	400
Below Thief River Falls	10	10
Below Crookston	25	30
Below Grand Forks	300	640

These values are sufficient to meet existing conditions and for the small increase in development expected during the next few years. It is expected that the extension of agricultural processing industries which may naturally follow installation of improved water supply will require an ultimate increase in the rates given by approximately 30 percent.

The values given represent the minimum rate of flow expected to be secured in at least 19 years out of 20. It is not economically practicable to secure these rates in the latter part of a 5-year drouth period, and under such conditions amounts of from one-half to two-thirds of those given must be accepted with consequent temporary decrease in sanitary standards.

The proper program for the realization of this plan will involve:

(*a*) Complete treatment of sewage and industrial waste within 3 years, expected to produce a reduction of biological oxygen demand of the effluents in an amount of 85 percent.

(*b*) Dependable regulation of stream flow to the extent of one-half of the values given within 2 years.

(*c*) Water conservation and stream flow regulation to produce the values given within 6 years.

(*d*) Provision for an increase of stream-flow rates by 30 percent within 15 years.

During certain of the wet years, the main stream flow values have nearly met the standards given above. During years of normal rainfall and run-off the total annual run-off has been ample, and the relatively simple storage of spring season flow would have permitted the proposed regulation throughout the year.

In this region, drouth-producing conditions appeared in 1920 with subnormal precipitation in parts of the basin and an excess of evaporation over the whole area. Stream flow was subnormal after 1922. After 1929, the total annual stream flow if completely conserved and regulated would have been insufficient to meet the standards set up. The water conservation plan must accordingly be designed to store water in wet years in

sufficient amounts to develop the regulated flows over a series of dry years but with some reduction in standards in the last year of a 5-year drouth.

Such long-time storage will be subject to great losses of which evaporation from water surface, when the rates are compatible with drouth conditions, is the most serious. For storage in shallow lakes these losses may represent so great a part of the impounded water as to require detailed analysis of each proposal.

In this drainage basin, natural storage facilities exist in the lakes of the Otter Tail Basin and in the Red Lakes, and to a certain extent in Lake Traverse. The out-flow from all of these lakes has until recently been unregulated. The present regulation dams on Otter Tail Lake and Red Lake are inadequate for the purposes here outlined, and have never been operated for the efficient regulation of stream flow.

As shown on the precipitation map, figure 4, the Otter Tail Basin lies in the area of highest annual rainfall. The rainfall in the drainage basin of the Red Lake is above the average for the Red River Basin as a whole. The topographic and subsurface conditions in these areas are favorable to further development at relatively small cost.

The committee has placed the Otter Tail project as first on the list, and the Red Lake project as the second. The Lake Traverse project has been extensively studied and is found to be inefficient for conservation purposes, and its development for that purpose alone is not justified, from the viewpoint of long-time water storage.

The hydrologic study indicates that water conservation for drouth periods must not only store water available at the time of spring thaws but must also be arranged to capture flood flows from the summer storms. The study of such storms indicates that short-time intense precipitation may occur during the summer in any part of the basin, and in any one year it is almost as likely to occur on the Dakota side as on Minnesota. It is desirable, therefore, that the conservation program involve also storage in the western part of the basin.

On the western side of the basin the best opportunities for water storage lie on the Sheyenne and the Pembina Rivers. Each of these streams emerges from the Dakota High Plains through relatively narrow valleys in which satisfactory dam sites appear to exist. Above these sites the streams have relatively large drainage basins and in spite of the low precipitation their annual discharge is considerable. There is also a storage possibility on the Goose River where the drainage basin is comparatively small.

On the Minnesota side effective storage can also be developed in material amounts through regulation of the outflow of small lakes near the headwaters of the Minnesota Wild Rice, the Buffalo and the Clearwater. Suggested studies may also indicate propriety of constructing artificial storage reservoirs in these valleys at points somewhat farther downstream than the natural lake outlets.

Otter Tail-Pelican Lake Storage Proposal.—The conservation of water in the Otter Tail basin should be carried out in the immediate future. The cost of this project is relatively small.

A proper regulation program for the many lakes will be flexible in character, and the project has the further unusual advantage of combining surface storage with subsurface storage. These lakes are to some degree "floating" on the groundwater table of the very extensive sands and gravel formations on which they are located; the raising of lake levels and the holding of the lakes at their normal high levels as long as possible will unquestionably result in the percolation of a considerable part of the surface water and the raising of the ground water table over a very large area.

While this natural percolation will result in great losses from the surface water during the first year or two, it is expected that a considerable part of the water lost to subsurface storage will reappear naturally as seepage to stream flow, and to this extent improved stream flow regulation will be to some degree automatic. It is also probable that the increased outflow from this aquifer to the headwaters of other streams such as the Minnesota Wild Rice, the Buffalo, and the Clearwater will naturally improve the characteristics of those streams, and through them be effective in the improvement of the Red River flow.

The other marked advantage of the Otter Tail project is that to the extent that water is stored underground it will not be subject to evaporation from water surfaces and, while transpiration losses may be increased somewhat on account of the elevation of the water table, the over-all efficiency of the subsurface storage should be greater than that of lake storage.

A program of installation of lake outlet control dams has been under way for the past 2 years and a number of installations have been completed. The completion of the program of lake control structures involves the installation of about 50 dams at the outlets of the lakes of the Otter Tail and Pelican chains. These dams will provide additional storage on these lakes of nearly 350,000 acre-feet and with projects already complete will bring up the additional storage available in the two chains to about 500,000 acre-feet.

These figures do not represent stored water that will be effective for release to improve stream flow, a matter which is analyzed in further detail in appendix A. The system of operation proposed in these studies treats Otter Tail Lake as the primary storage reservoir and considers the upper lakes of the Otter Tail chain as

secondary storage basins from which water is released to permit the functioning of Otter Tail Lake as proposed.

During the drought period the range in levels of Otter Tail Lake was only nine-tenths feet. The operating proposal presented increases this to 4 feet for extreme emergency conditions. Under this proposal the ordinary maximum high levels would be held at elevation 1,320.5. But during extreme flood inflows the level may be raised to 1,322 if necessary, which was the high water of 1897. The lake will be drawn down below 1,320.5 sparingly and depending upon the storage available in the upper lakes of the chain. During ordinary dry years it is expected that the draw-down will be as low as 1,319 and for extreme drought conditions might be 1,316.5, which is approximately the natural extreme low level under the conditions that have recently prevailed.

The studies indicate that the storage range proposed would have permitted a continuous discharge of about 23 second-feet, and this amount, if released in a way to supply deficiencies at Fargo, would have produced a dependable flow at that point of 35 second-feet subject, however, to losses from stream flow while the water is in transit. Except during drouth periods it is expected that satisfactory stream flow regulation can be secured with a range on Otter Tail Lake of not more than 2 feet with a possible increase of this range to 3 feet during single extremely dry years, and with the use of the full 4-foot range at the end of extended drouth periods.

Lakes of the Pelican chain have not been analyzed for operation in such detail. The studies indicate that for the purpose of producing effective storage for release during drouth periods the regulation of Otter Tail Lake will provide such storage to the extent of 45,700 acre-feet, and that even in dry years the control of the upper lakes of the chain will materially increase the effective storage, possibly as much as 20,000 or more acre-feet. Preliminary examination indicates that under a similar condition, the effective storage on the Pelican chain would be in excess of 25,000 acre-feet. With an allowance of from 10 to 20 second-feet for losses in transit, it is believed that the proper use of this stored water can assure a minimum flow at Fargo, during drouth periods, of 50 second-feet with possibly some reduction at the end of a long extended drouth. It appears that this can be further assured when additional control dams have been installed on a number of lakes in the chain not included in the group I project and when the regulation has been made more effective by the improvement of the channels connecting the various upper lakes of the chain.

Red Lake Water Storage Project.—The Red Lake project is highly meritorious because of the great amount of storage that can be secured by relatively small change in lake levels. The computations in appendix A indicate somewhat surprisingly that regulated stream flow in the Red Lake River could have been secured during the drouth period to the extent of 100 second-feet with no more lowering of lake level than actually occurred on account of the unregulated outflow. This project, therefore, combines improved stabilization of lake levels with improved low-water stream flow.

The storage phase of the Red Lake project requires only a moderate expenditure to carry out some reconstruction of the Red Lake outlet dam and control works. The operation of this project, however, will involve an agreement with the Indian authorities of the Red Lake reservation who have until recently resisted proposals for release of water from Red Lake during dry weather on the assumption that this would materially affect the value of the lake for fishing and for the cultivation of wild rice along the borders. It should be possible to show these authorities that the proposed regulation will actually be beneficial to their interests. The figures in appendix A show quite clearly that the withdrawal required from Red Lake to produce a dependable flow of 100 second-feet in the Lower Red Lake River would be equivalent to not more than an inch and a half in depth over the lake surface, an amount quite trivial when compared with very high losses from evaporation. On the other hand a properly operated control of the spring outflow should result in a much more stable level than has heretofore maintained. There appears to be no reason why a satisfactory operating program cannot be agreed upon.

Sheyenne River Projects.—The report of the United States Engineer Corps, previously referred to, sets out some studies for the construction of dams on the Sheyenne River, one of which is usually referred to as the Baldhill site, and at a site just above Valley City. It is shown that the dam at Sheyenne controls too small drainage basins to develop a definite water supply for carrying over during drouth months. It would, however, be of value for annual regulation and of benefit to the Upper Sheyenne Valley. The Baldhill proposal is a large drainage basin, and a high dam can be satisfactorily constructed at this point. The Corps of Engineers has recently completed a resurvey of the Baldhill Dam including the making of test borings, and a complete report on the proposed dam and reservoir is being prepared. It seems probable that a somewhat smaller dam than that originally proposed could have been operated throughout the drouth period to produce a regulated flow at West Fargo of at least 50 second-feet, and a very satisfactory water supply and sanitary condition in the vicinity of Valley City. The Baldhill proposal, while much higher as to cost of

water stored than the Otter Tail and Red Lake projects, is definitely important to the water plan as a whole. It appears possible that the proposal may eventually be extended to include the installation of hydro-electric power production.

Pembina River Project.—Preliminary surveys have been made by the engineering division of the Federal Emergency Relief Administration of North Dakota of a dam site on the Pembina above Walhalla. While no hydraulic computations have been prepared, it seems probable that a project here would be of about the same order as the Baldhill project on the Sheyenne. For water conservation it would be of value only to the towns of Walhalla, Neche, and Pembina, having an aggregate population of 1,752, and its principal importance is in connection with flood flow corrections; it will, however, materially improve low water flows north of the international border. It is discussed further in connection with flood correction.

Goose River Project.—Proposal for water storage on the Goose River has been only tentatively examined and requires further study. There is a definite need for a regulated flow in the Goose River for purposes of municipal supply and sewage dilution at the towns of Portland, Mayville, and Hillsboro. These towns have an aggregate population of 3,016 and have an acute water problem particularly at Hillsboro where a serious health hazard exists due to insufficient water for sewage dilution. A reservoir on the Goose River would supplement other projects in providing an adequate low water flow in the Red River at Grand Forks.

Tongue River Project.—Preliminary investigations have been made of a medium-sized storage reservoir on the Tongue River west of Cavalier for purposes of stream flow regulation. A regulated flow is needed in the Tongue River for purposes of water supply and sewage disposal for Cavalier and one or two other towns downstream. An alternate plan of providing a regulated flow in the Tongue River would be diversion from the Pembina Reservoir. Both these possibilities should be thoroughly investigated.

Aggregate Effect of Water Conservation Proposals on Stream Flow.—It should be understood that the conservation projects outlined are not expected to be effective to the extent shown except as they may have been in service during a wet cycle and so have maximum possible stored water available at the beginning of a drouth. To the extent that they are carried out during the next year or two their immediate effectiveness will be largely dependent upon the amount of water available for storage at the time of the spring break-up. However, even during recent drouth years it would have been possible to have conserved available water of the early months to an extent that the extremely critical conditions which occurred in the late summer and fall months would have been avoided.

The Otter Tail project if developed as to the 50 lakes contained in its initial and principal stage should provide a dependable flow at Fargo of at least 25 second-feet even though some phase of the drouth persists for several years, and the Otter Tail project developed to this extent should produce dependable stream flow of 50 second-feet at Fargo after several consecutive years of at least normal precipitation. Its ultimate development should appreciably increase this amount.

It is clear that this project alone will not result in securing satisfactory minimum flows at Fargo and it is essential that the Baldhill project on the Sheyenne be executed as soon as possible. This project if put in service during dry years will be even less effective than the Otter Tail in developing the flow ultimately required, but even in dry years sufficient water could be stored to provide further insurance against stream shortages at and below Fargo. (This assumes the provision of the dry weather diversion channel from the Sheyenne to the Red River above Fargo.)

The combined effects of the Otter Tail and Baldhill projects, when fully operative under conditions outlined, would guarantee a regulated stream flow at Fargo of approximately the amount shown in the preceding table, that is, an average of about 100 second-feet with, however, the same qualification that has been set out above with regard to the last years of a long drouth period.

In the last section of appendix A, Mr. Meyer has made an analysis with regard to the possibilities of producing a minimum flow of 200 second-feet at Grand Forks using only the Otter Tail and Red Lake projects. In this instance the 200 second-feet at Grand Forks was taken as representative of conditions at the end of an extreme drouth period. His studies indicate that the operation of these two projects would still leave a remaining deficiency below the 200 second-foot flow in an amount of about 590 second-foot-months equivalent to approximately 20 second-feet of continuous discharge and he shows that this might have been supplied by an emergency withdrawal from low water storage in the proposed Lake Traverse project of about 2 feet, which withdrawal would also have been effective at Fargo, or by withdrawal of an additional 1½ inches from Red Lake.

This study did not take into account the flow from the proposed Baldhill project, but indicates that with that project in service a minimum of about 230 second-feet could have been secured.

This study indicates further the ultimate necessity for the development of additional water conservation projects as for example those on the Minnesota Wild

Rice, Buffalo, and Clearwater Rivers and on the Goose River, if studies determine their practicability. It seems probable that, with certain of these projects in service and with the full development of the lakes of the upper Otter Tail chain, the desirable flows shown in the preceding table can be made dependable with possibly an occasional short time draft from Lake Traverse.

2. Transportation of Water as Regulated Stream Flow

The projected water storage sites are at relatively great distance from the points on the stream where dependable stream flow is required. The mere release at certain rates from the reservoirs will not necessarily produce the results desired. Except for the lower part of the Otter Tail River and the middle sections of the Red Lake River, all of the streams have flat profiles and sluggish flow. The present low water channels, when conveying the amount of water discussed here, will be wide and the velocity low. Even under the best conditions this operation will expose a very large surface to evaporation losses, and in critically dry years percolation from stream flow may be material.

For the operation of the water-supply program the best possible low-water stream channels must be provided and maintained. The importance of this part of the project has been well illustrated during the drouth by the differences between the 6 weeks required for the Otter Tail Lake water to reach Fargo under bad channel conditions as compared to the 11 days required after the channel had been cleaned somewhat under emergency conditions.

Mr. Charles L. Batchelder, district engineer, United States Geological Survey, has made an analysis of stream flow in the Otter Tail and Red River channels during the dry months of the year, and by comparison between discharges at various stations, has secured a rough approximation of the probable losses from stream flow resulting in some degree from percolation in the stream bed, but apparently to a much greater extent from evaporation and transpiration from the wide shallow overgrown low water channels. His memorandum is attached hereto as appendix C. It will be noted that losses in the Otter Tail and Red Rivers between Breckenridge and Fargo have been as high as 28 cubic feet per second.

For each of the projects involving water storage at a distance from the large cities, it is proposed that an efficient low water channel be excavated in the stream bed. In general these channels should be cut through the bars and along the flat reaches and should be of such width and depth as to permit the water to flow at the best possible velocity and to be delivered accordingly at the points of use in the shortest possible elapsed time. The total mileage of such channels is very considerable but their cost per foot for original construction is relatively small. The greatest problem will be that of maintaining channels after construction in good condition; undoubtedly there will be necessity for re-excavating portions of them after the occurrence of floods. Necessary maintenance can only be assured if an authority is set up definitely charged with the responsibility and adequately supported financially.

The most urgently needed low water channel improvement is that for the Red Lake River between Red Lake outlet and High Landing. Throughout the greater part of this distance Red Lake River meanders through a drained peat marsh and there is almost an entire absence of any definite low water channel; in consequence water released from Red Lake spreads widely and the losses are tremendous. A small emergency channel was constructed along this reach in 1934 with relief labor but it was little more than a scratch in the dried marsh and much more adequate construction is required to permit of satisfactory maintenance. The specific proposal for this part of the project involves also a more ample channel construction to permit of passing satisfactorily the heavier spring flood flows originating in this section, as well as those that will be released from Red Lake to prevent it rising to unsatisfactorily high levels.

The channel required along the Otter Tail River below Otter Tail Lake and along the Red River down to Fargo is of equal importanct although the present low water channel is not quite so unsatisfactory as that described above on Red Lake River. Along a part of the Otter Tail River below Otter Tail Lake the out-flow from the lake has been sufficient to permit a narrow marsh to persist. This marsh has supported wildlife in a small way and the Bureau of Biological Survey desires continuance of this marsh condition. This may be found feasible possibly through the construction of small levees along the proposed low water channel and with the definite released supply of some water to the adjacent marshes. However, during extreme drouth periods sufficient water may not be available over and above the needs for human consumption satisfactorily to maintain these small marshes and it may eventually be found best to transfer this minor wildlife conservation activity to some other area where the incompatibility of uses may not be so critical.

Eventually improved low water channels will be required for parts of the Red Lake River below High Landing and will be definitely required in the Sheyenne below Baldhill if a reservoir is created at that point. It is proposed also that a low water diversion channel be constructed from a point on the Sheyenne in southern Cass County to a point of the Dakota Wild Rice

River in order that a part of the regulated flow of the Baldhill Reservoir may be made available in the Red River above Fargo and Moorhead.

3. Dams in the Stream Channels

Dams in the Main Streams Prohibited.—During the drouth period in which a great number of streams have been dry for part of the year there has been a strong demand for construction of small dams in the channels of streams in order to catch and hold some water from spring flood flows and from summer storms at points where it was needed for municipal supplies, recreation, or for stock watering.

The small reservoirs so created are quite different in character from natural lakes. While the advantage of such construction to the particular areas suffering for lack of water appeared to be obvious and while the construction of such dams has served a useful emergency purpose, any further expansion of this program must be undertaken only after careful analysis.

These dams are objectionable from the viewpoint of the long-range water plan in two important respects:

(*a*) The impounding of water at small depths increases tremendously the already critical losses of water by evaporation and an over-extension of this program will, in many cases, result in dissipating all of the possible spring flow in this way and definitely deprive the towns down stream from such a system of the small continuous stream flows that otherwise might occur.

(*b*) Where such channel dams are of appreciable height and where the resulting lakes in the streambed occupy a considerable part of the volume of the streambed these dams will, in wet years, act appreciably to increase flood flows and flood damage. This condition is not generally apparent to the layman as it may appear that the dam itself is a relatively small obstruction in the stream. Actually, the increased flood flows are not so much the result of the obstruction from the dam as they are due to the fact that with the dam in place and the lake created behind it the bed of the stream is already appreciably occupied when the flood comes down. Consequently, the flood flow is not diminished through the necessity of filling up the valley as it would be in the state of nature, but passes on down the stream in full volume.

It should be apparent that when regulated stream flow has been secured and the stream passes such points in considerable and dependable volumes, the need of those dams largely disappears.

From the above considerations it is apparent that no additional dams should be constructed in the channels of those streams used to transport the principal water supply from the effective storage areas to the cities for which the supply is intended. There should be a definite prohibition against such construction on the Otter Tail River, on the Red River below the Otter Tail, on the Sheyenne below Valley City, and on the Red Lake River. On all of these streams the only dams permissible should be those required for municipal water supply intakes and even these should be restricted to relatively small heights, providing a few days' local storage. An exception to this rule would apply to a diversion dam in the Sheyenne in order to divert low-water flow to the Red River above Fargo and an exception could also be made as to dams on the steeper section of the Otter Tail for water power purposes where the storage would be of good average depth.

Whenever a dependable stream flow is secured, existing channel dams should be removed as far as possible and others might be reduced in height.

Dams on Other Streams Encouraged.—The above discussion relates to those dams that would not only be useless in a desirable conservation plan, but which would, on the contrary, definitely operate to dissipate part of the water supply. For those streams not useful as principal transportation channels for the conveyance of stored water and particularly for those streams which are normally dry during the latter part of the year a program of construction of small dams is definitely desirable. These dams would store water available in the streams during the spring months and would fall in the two principal classes.

The first class would include dams of considerable size at points on the stream where the run-off from the basin would assure their being filled up to the midsummer period. These dams would be equipped with properly controlled outlets that would permit the release of stored water in a small way to maintain stream flow during the late summer and fall. Some of these would act to contribute an appreciable amount of water to the flow in the Red River, others would be effective principally to maintain some water in their own substreams, and many would be useful as a source of water supply for the smaller cities and towns.

The second class would include a large number of much smaller structures located well up on the small tributaries and need not necessarily be equipped with outlet controls. They would primarily be useful for stock watering and for rural water supply in their immediate vicinity and would be useful to that extent throughout the year only in years of normal or supernormal precipitation. During dry years they would probably not be effective for this purpose beyond the month of July.

The program of dam construction of either of the above classes requires careful supervision, not only as

to their location and size but to insure sound engineering in construction and the provision of adequate spillways.

4. Subsurface Water for Small Town and Rural Supplies

Most of the small towns of the valley now secure their water supply from wells and practically all of the rural supplies are from such sources. This situation is discussed in some detail in the various subbasin reports. The information there presented indicates that there has been a general lowering of ground water over a large part of the basin, that the yield of a great number of the wells has been greatly reduced and many have become dry.

For parts of the area where no other source of supply can be made available, it is essential that measures be taken to restore the ground-water levels so far as this may be practical. To the extent that levels may have been permanently lowered, a general program of deepening of individual wells will be necessary.

For the southeastern section of the basin the general program of water conservation outlined in the first section of this report may be expected appreciably to improve subsurface supplies. In isolated sections where wells penetrate lenses in the lacustrine deposits, a general improvement in levels may be expected as part of the general recovery from the drouth. In some instances this improvement may be accelerated by the program of small storage dams and the resultant percolation of impounded surface water to the groundwater table. Apparently a large number of wells have taken water from isolated and relatively small areas of sand in regions of otherwise tight soil and for these sections small impounded surface supplies appear to be the only practical remedy.

The tables attached to the subbasin reports show numerous analyses of well water. Apparently more than three-fourths of the subsurface supply is of unsatisfactory quality. Quite generally the mineral content is far above desirable water standard for household use. In many cases it is so high in sulphates as to be unsatisfactory for any purpose. In the southwestern quarter of the basin, generally in the subbasin of the Dakota Wild Rice and that of the Sheyenne, the water contains excessive amounts of fluorides resulting, in some sections, in a nearly endemic condition of "mottled teeth" among children. Where this occurs, a replacement of the supply by impounded surface water is the only complete remedy although experiments now in progress indicate that the removal of fluorides may ultimately be commercially practical at least to the extent of providing small amounts of fluoride-free water for drinking purposes.

The situation throughout the basin with regard to subsurface water supply is so definitely unsatisfactory as to justify its becoming a major part of the long-range plan of water improvement. This requires an investigational project which should be organized in three principal stages:

First, a very detailed reexamination of subsurface water throughout the basin with regard to both quantity and quality and a determination therefrom as to what subsurface supplies may be made dependable in both respects.

Second, for those areas where subsurface water is not subject to satisfactory readjustment, a detailed engineering investigation of the best means of providing impounded surface water and improved stream flow in such manner and in such locations as to make surface water readily available to supplant the unsatisfactory groundwater supply.

Third, in order to bring about a basin-wide improvement in small town and rural supplies it is essential that the results of the investigation above be made readily available to the small town and rural population. This will require a continuing service furnished jointly by the State geological departments, State water engineers, and the public health authorities, possibly acting in cooperation with the tri-State water authority recommended elsewhere in this report.

As all of the principal towns are located either on the main streams for which a satisfactory improved stream flow is provided in the proposal under topics 1 and 2, or on the larger lakes, the situation outlined above will apply only to the smaller towns and the rural areas.

5. Stream Pollution Abatement and Urban Water Supply

The proposals set out in topics 1 and 2 of this report should make available stream flow in the principal rivers in an amount far in excess of the municipal water consumption, the recommended amount having been determined by the need for the dilution of pollutional wastes and not by the aggregate of municipal water works' requirement.

As shown in topic 1, the recommended minimum stream flows are based on the expectation of the greatest possible diminution in the discharge of pollutional wastes. Accordingly, the general water plan for the valley involves, as an essential part, treatment of domestic and industrial wastes before discharge to the streams.

During the recent drouth some of the cities have taken advantage of Federal grant possibilities and have financed and constructed sewage treatment works of adequate design, others are still discharging raw

sewage. Industrial wastes are being discharged in large quantity at West Fargo and at Grand Forks now, and to a minor extent, at a number of other places. The installation of high-degree treatment for all remaining wastes is an essential part of a long-range water plan and program and its consummation should be definitely guaranteed before large sums are expended for the improvement of stream flow. The cities and towns where sewage and waste treatment are needed are shown in the project lists, one group containing those where the treatment should be undertaken at once, and in a second group those cities whose pollutional effluents would not immediately affect the water supply of the cities in a serious way but where, nevertheless, the pollution should be abated within relatively a few years.

This criterion applies to towns even as small as 500 population, except that where certain of these towns are definitely retrogressive and the population may be expected to diminish rapidly, it is obviously impractical to finance high-grade treatment and an installation of a more temporary and less expensive character seems to be indicated.

With the reduction of pollution of the waters of the streams, and with the determination of adequate sources of water supply, the further installation of waterworks and extension of water facilities may be expected to proceed rapidly. Many cities, even the small ones, will ultimately be able to afford a water of higher quality and will be expected to undertake somewhat more expensive processes of water treatment including, quite generally, water softening.

6. Water Areas for Recreation and Wildlife Conservation

The recreational assets provided by the many lakes of the Otter Tail-Pelican chain have already been mentioned. It has been shown that during the drouth period their use has been seriously impaired because of the recession of lake levels and a consequent exposure of muddy and unattractive shore lines during a considerable part of the summer and fall season. It has already been shown as to certain of the lakes that their levels could be controlled to an extent necessary to develop effectively stored water and at the same time definitely avoid the more serious fluctuations which have occurred.

In their unregulated state these lakes often rise to unsatisfactorily high levels during the late spring and because of the unimpeded outflow rapidly lower to undesirably low stages. The water conservation plan provides for a type of operating control which will greatly increase the recreational value of the lakes used for storage purposes. While this condition applies to the Otter Tail-Pelican chain and to the control of Red Lake, there seems to be no question but that a similar operating development can be worked out for a great many other small lakes, some of which have actually been dry during a considerable part of the drouth years.

In addition to the recreational and wildlife values which will result from the stabilization of existing lakes, the plan is in accord with proposals for the restoration of certain marsh and lake areas which heretofore have been drained. This applies particularly to Mud Lake and Thief Lake now being restored by the Biological Survey and to some extent to the restoration of marsh areas along the divide between the Red Lake River drainage and the Lake of the Woods drainage. The operation of the Mud Lake and Thief Lake projects, however, should provide for regulation and should permit of the release of some water for urban use under extreme emergency conditions.

The largest project coming under this general head is that for the restoration of Lake Traverse. The characteristics of this lake have been described in detail in the Simons-King report already offered as reference. During the drouth the lake practically dried up. Hydrologic studies which have been carried out indicate that with the construction of a dam at the head of the Bois des Sioux it should be possible to restore this lake during a wet cycle and to maintain it throughout a 5-year drouth period similar to that of the last 5 years, provided no water is withdrawn from the lake for the purpose of stream flow regulation. Because this is the only possible large lake area in the south-central section of the basin, and because of the fine possibilities for the development of wildlife refuges on certain of the lake arms, the project appears to be particularly desirable and should be given serious consideration provided that a considerable part of the cost can be charged against the recreational and wildlife uses. The project can also be developed so as to have an important advantage in the correction of flood flows in the Red River and is discussed further under that head.

On the Dakota side of the basin there is a marked absence of water areas for recreational use and the plan contemplates the development of a number of small lakes, primarily for this purpose, in locations where they will not seriously interfere with the major proposal for water conservation for the purpose of stream flow regulation. All proposals for such recreational and wildlife lakes on the Dakota side should be carefully studied in this report.

7. Flood Flow Correction

Studies and plans for the reduction of the flood volumes and of resulting flood damages have been carried out in the past for various parts of the basin. The

most complete and important study is embodied in the Simons-King report of 1922 on the Red River itself. Other studies have been made for the Red Lake River. The matter is complicated by the international problem which required that there should be appreciable increase in flood volume or stage at the Canadian border.

The Simons and King report presented a plan of flood reduction involving the impounding of flood waters behind a dam in Lake Traverse, the diversion of a part of the flood flow of the Dakota Wild Rice River to the channel of the Sheyenne River, and the reduction of the flood heights between the mouth of the Sheyenne and the Canadian border by partial clearing of the flood channel and the removal of restrictions, including the reconstruction of certain bridges.

Another study has been carried out in detail by the United States Geological Survey, for the International Boundary Commission, with regard to floods in the Roseau River.

Justification for the Lake Traverse flood storage proposal was involved primarily by the reclamation of wet lands along the Bois des Sioux, on which the original report placed a benefit of $12 per acre. At the present time the values of the lands to be reclaimed are low; these lands are largely in wild hay and apparently could not stand a benefit assessment of more than $1 or $2 per acre although the ultimate benefit might be fixed at $5 per acre. The lateral drainage ditches required for that reclamation are not now justified but may be accepted as a possible part of a long-range plan.

The carrying out of the Lake Traverse project as set up herein involves a considerable capacity for flood storage and this project could be effective greatly in reducing the frequent minor floods along the Bois des Sioux; it will not prevent the infrequent overflow of these lands by major floods. The project will have some minor effect in reducing flood flows in the Red River below Fargo and has definite value in the flood correction plan as a whole. It cannot be justified on the basis of flood correction alone but is definitely desirable as a multiple-purpose project and accordingly is accepted as a part of the flood-control plan.

In connection with the water conservation plan there is proposed a reservoir on the Sheyenne below Baldhill Creek. This reservoir, if built, should contain capacity for the storage of flood flows. It might very nearly regulate the flow of the Sheyenne and remove the flood flows of the Sheyenne from the Red River except for major and infrequent floods.

There is no possibility of impounding flood waters economically on the Dakota Wild Rice River but if the reservoir on the Sheyenne is built the diversion of a part of the flood flow of the Wild Rice to the channel of the Sheyenne, as recommended by Simons and King, will be of considerable value in reducing the flood plane at Fargo.

The regulation of the lakes of the Otter Tail River, as proposed under the water plan, will slightly reduce the flood flow of the Otter Tail and, in a small degree, of the Red River itself.

There appears to be a possibility for the construction of multiple-purpose dams on the Minnesota Wild Rice. If such projects appear to be economically justified for water conservation they will also have appreciable value in flood flow correction.

The regulation of the Red Lake River flow, as proposed for water conservation, fits in satisfactorily with a flow-control plan and an appreciable part of the cost of this regulation can be charged against benefits in flood correction. Full development of the Red Lake River for flood protection will require some additional leveeing in the vicinity of certain cities in the lower part of the valley.

There appears to be a possibility for the storage of water on the Pembina River just above Walhalla. If this project is developed it may be so designed as to have a definite flood control benefit for the lands along the Pembina itself. As the Pembina discharges into the Red River at the Canadian border a reduction of flood flow of this tributary will produce a lowering of the flood plane of the Red River in the United States only through reduction of stage in Canada.

The character of the flood damage in the Roseau River Basin is unusual and peculiar and of such frequency as to justify a considerable expenditure for correction. The Roseau River project, as set up here, is largely independent of the Red River problem as a whole, but a diversion of its flood water directly to the Red River through Two Rivers will require compensation by reduction of flood flows from other tributaries, possibly from the Pembina.

The floodway of the Red River at and below Fargo is seriously impeded at certain points by bridges, and throughout its length by heavy timber. The condition of the overhanging trees along this stream has a desirable effect in shading the Red River channel and in inhibiting the growth of woods and willows in the streams. However, when the low water flow in the Red River has been increased through regulation as proposed in this plan, advantage of a shaded channel will be less important. The flood correction plan involves the clearing of heavy timber within the high-water channel of the Red River for a distance of 30 feet back from the water's edge on each side.

Summary.—The plan of flood-flow correction proposed in this report follows generally that which was

studied in detail in the Simons-King report, but with important exceptions as follows:

(*a*) The Lake Traverse project is now proposed as a multipurpose project for recreation, wildlife conservation and, to a minor degree, water conservation for stream-flow regulation and a considerably smaller portion of the capacity is assigned to flood-flow retention than was originally proposed. As a result of this it will protect the lands along the Bois des Sioux from the smaller floods and will reduce the frequency of flooding, but will give very slight protection against great and infrequent floods. In accordance with this plan the outlet channel along the Bois des Sioux is made appreciably smaller than originally proposed, being given a capacity of about 500 cubic feet per second.

(*b*) The inclusion of the water conservation reservoir near Baldhill Creek on the Sheyenne materially changes flood-flow characteristics in the Sheyenne Delta. While it is not proposed that this reservoir will have flood-detention capacity for the greatest floods, it should nevertheless practically control flood-flow except for infrequent occurrences and will greatly improve the condition of lands in the Sheyenne Delta and along the lower Wild Rice and will leave the present channel of the Sheyenne nearly empty during moderate floods.

(*c*) The situation above described under (*b*) adds great value to the still included Simons-King proposal for floodway diversion from the Dakota Wild Rice to the Sheyenne and the three proposals included in (*a*), (*b*), and (*c*), with some added advantage from the flow-regulation project on the Otter Tail which will relieve the valley above the mouth of the Sheyenne from flooding except at very long intervals—possibly 15 to 25 years. The definite value of these benefits can be determined only after the best proposal for the Sheyenne Dam has been worked out and when full hydrologic studies have been completed with regard to the combined effect of these projects. Full protection at Fargo can be reasonably assured by the removal of some of the constructions within the floodway within that city and by the reduction in height of the intake dams in the Red River channel.

(*d*) The above proposals will materially improve flood-flow conditions between Fargo and the Canadian border, which may be expected to receive further improvement through the operation of the Red Lake River project and possibly by the impounding of water on the Goose River and the Minnesota Wild Rice River. A reasonable degree of protection, however, requires the improvement of the floodway channel of the river very much as outlined in the Simons-King report, but the amount of channel clearing required can be somewhat less than originally suggested. This channel clearing is carried in the project list and includes not only the removal of timber along the lower part of the banks but the reconstruction of bridges and other structures within the floodway. The project was given a tentative estimated cost of $2,000,000, a large part of which is chargeable against bridge and structural rehabilitation. It is expected that the ultimate cost will be materially less than the amount stated.

(*e*) While needing definite hydrologic evaluation it seems probable that even with the floodway between Fargo and the border, flood waters will result at the border in somewhat larger amounts than have heretofore occurred and possibly under some conditions at slightly higher stages. In order to avoid international complications on this account, the proposal for flood detention on the Pembina River at Walhalla is valuable as it may be so operated as fully to compensate for any increased flood volume or flood stage at the border that might be otherwise brought about.

General.—The various proposals discussed above are included in somewhat more detail in connection with the project statements. It is expected that as each of the projects is developed for its specific purpose an over-all investigation will become necessary as to their integrated effect on flood flows in the Red River itself. Such investigation should also include a study of further measures for flood protection that may be justified on the lower Red River and the effect of the diversion proposed in the Roseau project in discharging additional flood waters through Two Rivers.

To the extent that frequent flooding in the lower Red River has been due to the arrival of flood peaks in the southern end of the basin at a time when the northern section of the river was still icebound, particular attention should be devoted in connection with floodway clearance to the avoidance of the possibilities of ice gorges.

8. Land Drainage

For the Red River of the North Basin the drainage of agricultural lands enters into the long-range plan in four phases as follows:

(*a*) The correction of drainage systems in certain instances where the drainage is necessary during wet years but in its present state is defective in that it at times receives flood flows from the streams and distributes flood water on the lands to the definite detriment of agriculture.

This phase appears as a major difficulty in an important way with regard to the agricultural lands south of the Roseau River. It occurs to a minor extent in other instances where flood waters occasionally escape from streams and follow drainage ditches to other outlets. A case of this type exists in the vicinity of Ada. The correction of these situations is related to

the problem of correction of flood flows as well as to land drainage.

(*b*) The plan involves the maintenance of drainage channels in good agricultural lands. This is primarily a responsibility of the counties. At the present time the maintenance has been neglected to such an extent that the channels are obstructed by tree and weed growth, and in some cases are so nearly filled with soil as to require complete rehabilitation.

(*c*) A very large area, primarily on the Minnesota side, has been supplied with drainage facilities although the drainage never was economically justified because of the unfertile soil. The plan requires that the drainage structures in these areas be blocked and in some cases provided with controls so that such areas may be returned at times to the status of marshes and quite generally abandoned for agriculture. This phase of the drainage plan is definitely related to that part of the water plan dealing with wildlife conservation.

(*d*) The long-range plan includes the installation of land drainage for areas of good soil not now so provided. At the present time there is little undrained land for which the installation of drainage would be economically justified, but it is visualized that with the further development of the valley some areas should be taken out of wild hay production and placed under cultivation for crops of greater value. The lands along the Bois des Sioux are in this category, and in this instance the drainage would be related to the plan for water conservation and stream-flow correction and to that part of the plan dealing with flow correction.

9. Hydroelectric Power

Hydroelectric power development in the Red River of the North Basin does not come into the water plan as an item of major importance. However, at present there are a number of small installations on the Otter Tail River and on the Red Lake, Clearwater, and Wild Rice Rivers, all in Minnesota. The proposed plan of stream flow regulation will affect the operating possibilities of these plants to a very considerable extent and may justify the installation of additional capacity at the present plants and ultimately may justify power production at other sites.

At the present time six plants on the Otter Tail River have installed capacity of about 8,000 horsepower and plants on the Red Lake River of over 3,000 horsepower. Most of these plants are interconnected with other plants involving steam production, some of them using the cheap lignite fuel of North Dakota.

Prior to the beginning of the drouth in 1930 the plants had a considerable and dependable output. It appears that they were operated to capacity during the months of heavy stream flow and as a result their greatest output was for the months of March to July, inclusive. However, with the regulation then available in Otter Tail Lake, plants were able to carry a fair load throughout a considerable part of the remaining months of the year.

During the drouth period, available regulation was not sufficient to permit of any appreciable annual equalization and most of the plants were practically out of service after the month of June, being operated as standbys to the extent that the small storage in their ponds permitted.

As an example of the importance of this situation, the output of the six plants on the Otter Tail River during the year 1927 was approximately 16,500,000 kilowatt-hours and during the year 1933 the output was only about 1,700,000 kilowatt-hours, a reduction of approximately 15,000,000 kilowatt-hours. When the proposed plan of storage in the Otter Tail-Pelican system is effective the dependable flow through these plants should be approximately 50 second-feet although reduced possibly to 30 second-feet in the latter years of a long dry cycle. This condition will permit these plants to become operative in a dependable manner and to even better advantage than was possible during the wet years with only the natural storage of the lakes available.

With the regulated stream-flow effective in this manner it seems entirely possible that these plants might be operated to advantage for peak load production in such way as to defer for sometime further expansion of stream facilities or to avoid any large importation of power into this area. The record of total power production indicates a rather steady increase even during the drouth and depression period, and there will apparently be a further steady increase in power demand for some time. If the regulated stream-flow did nothing more than permit a production recovery in these plants to the 1927 level and if that part of the recovery which might be due to the better stream-flow regulation were evaluated as peak load power it is obvious that there would be a very considerable return on the operation of the water plan as a whole from this particular phase.

In addition to such redevelopment of production it would seem entirely probable that the dependable stream-flow would justify some increase in installed capacity at the present sites. It is also possible that further investigation will indicate the propriety of hydroelectric development at certain other undeveloped sites on the Otter Tail River for which there seem to be six possibilities worthy of consideration with a total aggregate head of between 50 and 100 feet.

The present installations on the Red Lake River are less extensive but the possibilities of further development may be quite as attractive as on the Otter Tail.

The Baldhill project on the Sheyenne, if operated for flood detention and stream flow regulation, might well justify the installation of hydroelectric production using a regulated flow of 40 to 50 second-feet with a mean head of possibly 40 feet. If the Walhalla project on the Pembina River is shown to be warrantable for flood-flow correction and water conservation, a somewhat similar installation may be indicated there.

To the extent that hydroelectric power production is improved or made feasible through the stream-flow regulation phase of the water plan, the resulting benefits should be evaluated and the return from this source should be made available to the interstate operating authority and might well pay a very considerable part of the maintenance and operation of the water plan as a whole.

A study project has been set up to provide for a survey of power production possibilities and improvements which might grow out of the operation of the water plan and, if indicated by this survey, a request should be made to the Federal Power Commission for an evaluation of the benefits to hydroelectric power.

10. Summary of the Water Plan

The principal water requirements for the basin are:

(*a*) Storage in natural lakes and in reservoirs located around the rim of the valley, and regulated release of surface water to produce the stream-flow necessary for water supply and the dilution of wastes, incidentally involving some improvement in hydroelectric power production.

(*b*) Development of certain low-water stream channels for the efficient transportation of the dependable flow to and through the central portion of the valley.

(*c*) The conversion of unsatisfactory ground water supplies of the smaller towns to more satisfactory subsurface sources or to surface supplies.

(*d*) Correction of flood-flow conditions along some tributaries and on parts of the Red River.

(*e*) Restoration and stabilization of water areas for recreation and for the conservation of wildlife.

(*f*) Rehabilitation of drainage works of certain fertile agricultural lands and the restoration of lands uneconomically drained to their natural condition.

(*g*) Construction of small dams on normally dry streams for stock watering and other rural purposes.

(*h*) After a determination of the details of stream-flow regulation, a study of the warrantability of additional hydroelectric power production, a study of the improvement to power production resulting from stream-flow regulation at existing plants and an evaluation of the resulting benefits.

11. Interstate Authority

Interstate Control.—The urban population of the area is well divided between Minnesota and North Dakota. The more important sources of the water to be distributed are in Minnesota. Flood storage in North Dakota is necessary to the complete plan. The project, if carried out, can be effective only if operated in the two States for the best interests of the valley as a whole, and the maintenance of low-water channels continuously in adequate condition can only be guaranteed by an over-all authority.

Accordingly it is essential to this project that a permanent interstate agreement for the development and operation of the water plan be effected and that some authority be set up having a guaranteed financial support, adequate to meet a part of the cost of construction and efficiently to operate and regulate storage and movement of water.

Interstate Authority.—The struggle to secure relief from devastating floods and to increase water supplies for municipal and industrial purposes along the Red River of the North dates back 30 or more years.

Following the historic floods of 1919, joint legislation was passed by the States of North Dakota, South Dakota, and Minnesota authorizing the formation of drainage and flood control districts in drainage basins common to two or more States. In attempting to apply these statutes, however, it was found that differences in basic laws of the three States made it impracticable equitably to determine benefits and damages and assess the costs against lands and interests in the three States. The plan at that time was to assess all costs against individual pieces and parcels of land which might be benefited.

As a result of past experience to establish interstate cooperation, certain definite conclusions can be stated.

1. An interstate authority is necessary. It should have power to receive and expend moneys in all three States. This authority should be simpler and more direct in its application than the present statutes authorizing formation of interstate drainage and flood control districts.

2. The interstate authority should not attempt to assess costs of operation and maintenance of water conservation works against individual pieces and parcels of land that may be benefited. Such authority should levy costs against the taxing units in which benefited interests are located, as for instance, townships, counties, and organized cities and villages. Each of said taxing units can then be made responsible for the levying and collecting of whatever contribution it is to make to the interstate authority. For instance, the equitable portion of the costs of maintaining and operating the water conservation district having been determined by the interstate author-

ity, it should have power to look to the city of Fargo, as a municipality, for the payment of its contribution. So also should any other city, village, township, or county be dealt with as organizations. Under such a system, machinery can be provided separately in each State, if it does not already exist, for the spreading of assessments within a city or other political unit, equal in total to the levy made by the interstate authority. Thus the difficulties can be avoided which arise by reason of differences in basic procedures practiced in different States.

3. Since the water to be conserved will often be stored in one State and used in another any equitable plan must place the burden of costs in proportion to the benefits to be received. This policy must be applied not only to operation and maintenance, but to the construction of necessary structures and the provisions of rights-of-way and flowage as well. Unless a genuine showing is made that such equitable distribution is intended and specified by the act to create an interstate authority, it is certain that widespread opposition will develop against any plan which purports to store and control waters within one State for the benefit of the communities in other States.

4. In order to receive general public approval in localities of origin any act to create an interstate authority will have to insure (*a*) representation on the interstate authority of a character that will adequately protect their interests, and (*b*) procedures for the award of damages and assessment of costs in proportion to actual damages suffered and benefits received. From past attempts to develop and operate emergency projects for supplying water to distant municipalities, as for instance, in the case of bringing water from the Otter Tail chain of lakes to supply Breckenridge and communities below, interests residing around the lakes from which water was to be taken, indicated quite clearly that they look askance at any plan that would impose inequitable burdens by way of supplying flowage and other water conservation needs, without some form of compensation. Similarly, the interests of the Red River Indian Reservation must be protected.

In the absence of such agreement, the full consummation of the plan could not be reasonably assured.

12. International Aspects

International Aspects.—The Red River of the North rises in the United States and flows across the international boundary into Canada between Pembina, N. Dak., and Emerson, Manitoba, and continues past the city of Winnipeg to Lake Winnipeg and thence through the Nelson River into Hudson Bay. Thus, the water flowing in the Red River becomes of international importance and in proposing any projects involving the control and use of this water by the people on either side of the international boundary, the interests of the people on the other side must be protected in accordance with the treaty between the United States and Great Britain, signed January 11, 1909.

There is no water power development anywhere along the course of the Red River in Canada, but for more than 60 years the river has been continuously used for navigation from Lake Winnipeg up to the city of Winnipeg. It was formerly navigable along its entire length, and it is still used considerably for this purpose, to a short distance above Winnipeg. For more than 25 years this has been facilitated by a dam and lock on the river at St. Andrews, about 20 miles below Winnipeg. The dam is a rather unusual type of roller-slat curtain through which there is unpreventably so much leakage that at very low stage there is some difficulty in keeping the depth up to navigation requirements.

The river is used at some points for municipal supplies, and at many points along its length sewage is turned into it either with or without purification treatment. For these reasons very small minimum flows are quite undesirable.

There are few portions of the valley in Canada where flood-flows of ordinary height pass out of the channel enough to cause more than minor inconvenience, but at longer intervals floods occur of sufficient height to cause damage and serious losses to adjacent farm lands and to municipalities, particularly Winnipeg, which is the fourth largest city of the Dominion of Canada.

Thus it appears that an increase in the amount of frequency of flood-flow could not be advantageous to Canada under any conceivable condition, but quite often an increase in quantity of flow during low-stage periods would be advantageous and acceptable. For every reason the valley residents and municipalities along the Red River in Canada prefer a flow as nearly equalized in amount from month to month and year to year as may be practicable. And that is precisely the chief intended effect of most of the proposed projects in the prospective water plan for the Red River in the United States. Every part of it will have a tendency to reduce the maximums of flood periods, or to increase the flow during the low-stage periods, or both, but none of the items can have the opposite effect.

Therefore, as a whole and in detail this plan should meet the enthusiastic approval of every Canadian municipality along the Red River, of the Manitoba government, and of all citizens who happen to be at all affected.

So far as announced, there have been no formal agreements or contracts pertaining to this matter enacted or authorized by any of the Canadian officers, bureaus, or departments. But for 25 years past, in-

formally or unofficially, in verbal consultations and conferences, addresses at public meetings on either side of the boundary, and likewise, complete approval of such a movement as this and promises of any feasible cooperation have been repeatedly expressed by the responsible parties or leading citizens north of the boundary, such as successive mayors of Winnipeg, provincial conservation commissioners, chief engineers of the Dominion water power and hydrometric bureau, and others.

Thus the endorsement of any such movement as this taken as a whole, and for all of those parts except possibly some trivial detail easily amended, can be assured.

STAFF REPORT—SECTION IV
PROJECTS AND PROGRAM

Description

In this chapter an attempt has been made to list all projects. The tabulation shows the estimated cost of each project and indicates its present status. These figures are somewhat higher than the original estimates as used in compiling the list of projects in July; but it is advisable to make the correction so that all the records will be uniform.

Form F–72 has been completed for all of the Minnesota projects and complete detailed information may be obtained on any project listed by referring to the record.

While the list is quite complete today, it should be noted that changes will occur by reason of the completion of some projects and the abandonment of others. Many projects recommended in the first report have been completed. Also new projects not on the list are being suggested almost daily. It is hoped, however, that the list as given here will serve as a guide for projects to be undertaken in the Red River of the North drainage basin.

Revised Summary of the Red River of the North Project List

GROUP A. FOR IMMEDIATE INVESTIGATION AND CONSTRUCTION

1. Investigation Projects

General:	
United States Army Engineer's survey on merit of plan and feasibility of projects; to include Baldhill, Walhalla, Steele County, Dakota-Wild Rice floodway to Sheyenne River, Sheyenne-Dakota Wild Rice diversion ditch, Park River levee channel improvement, which survey is now under way	[1] $50,000
Water conservation and flood control:	
Study of floodwater channel, Red River below Otter Tail	20,000
Surveys and development of plans, small conservation dams	20,000
Water power:	
Study of the Otter Tail, Red Lake, and Sheyenne Rivers	5,000
Water supply:	
Investigation of ground water supply of small towns	40,000

2. Construction Projects

General:	
7 stream-gaging stations	25,000
Water conservation and flood control:	
Red Lake River, channel improvement and control works	780,000
Baldhill Reservoir on Sheyenne River	780,000

[1] Projects included under these items are in various stages of development. Some are under construction, others are recommended; surveys are completed for a number and other surveys are underway.

Revised Summary of the Red River of the North Project List—Continued

GROUP A. FOR IMMEDIATE INVESTIGATION AND CONSTRUCTION—Continued

Water conservation and flood control—Continued.	
Sheyenne River, low-water channel improvement	$100,000
Sheyenne River, diversion including dam	95,000
47 small dams in sub-basin of Otter Tail-Pelican Rivers	[1] 450,000
39 small dams on Wild Rice, Sheyenne, Goose, Pembina Rivers in North Dakota; on Red, Snake, Roseau Rivers in Minnesota; and Marshall County in South Dakota	[1] 550,000
Snake-Roseau Reservoir and diversion	1,300,000
Otter Tail-Red Rivers improvement low-water channel	[1] 260,000
Water-supply projects:	
Water supply and water treatment plants in 133 municipalities	[1] 2,600,000
Pollution projects:	
Sewer systems and sewage treatment plants in 61 municipalities	[1] 2,600,000

GROUP B. FOR DEFERRED CONSTRUCTION

Water conservation and flood control:	
Park River levee and channel improvement	$45,000
Goose River Reservoir	195,000
Walhalla Reservoir on Pembina River	395,000
Dakota-Wild Rice floodway to Sheyenne River	350,000
General—Wildlife:	
Lake Traverse to Bois des Sioux	1,400,000
Tongue River Reservoir, Pembina County, survey completed	100,000
Additional storage, Sheyenne River, Nelson County	100,000
Stump Lake improvement, not surveyed	50,000
49 small dams and reservoirs for water conservation, recreation and game refuges, listed in class C	[1] 200,000
Channel improvement Red River (Fargo) to Canadian border	500,000
31 municipal water supply and treatment plants and sewerage and sewer treatment plants listed in class C	700,000
Total	13,710,000

Details of Major Construction Projects

GROUP A. FOR IMMEDIATE CONSTRUCTION

Water conservation and flood control:	
47 small dams in the subbasin of Otter Tail-Pelican Rivers	$450,000.00
Many Point Lake, Round Lake, Height of Land Lake, Sybil Lake, Rose Lake, Scalp Lake, Six Lake, Carroll Lake, Silver Lake, Dead Lake in Becker County, Big Pine, Boedingheimer Lake, Marion Lake, Buchanan Lake, Dead Lake in Otter Tail County, Star Lake, Round Lake, Big McDonald Lake, Alice Lake, Elbow Lake, Blanche Lake, Mollie Stark, West Battle Lake, Clitheral Lake, Crane Lake, Stuart Lake, East Lost Lake, West Lost Lake, Wall Lake, Big Floyd Lake, Detroit Lakes, Sallie Lake, Hand Lake, Bucks Mill Pond or Melissa Lake, Maud Lake, Lake	

Revised Summary of the Red River of the North Project List—Continued

Details of Major Construction Projects—Continued

GROUP A. FOR IMMEDIATE CONSTRUCTION—Continued

Eunice, Mud Lake, Leek Lake, Bucks Lake, Holbrook Lake, Little Pelican, Big Pelican, Lida Lake, Franklin Lake, Lake Lizzle, Long Lake, Reed Lake.

8 small dams in the subbasin of Otter Tail-Pelican Rivers have been completed or are under construction as follows: Big Pine, Rush Lake, Otter Tail Lake, East Battle Lake, Little Floyd Lake, Bucks Mill Pond or Melissa Lake, Lake Eunice, and Franklin Lake.

39 small dams on Wild Rice, Sheyenne, Goose, Pembina in North Dakota; on Snake, Roseau Rivers in Minnesota; and Marshall County in South Dakota ---------- $550,000.00

Buffalo River outlet of Rock Lake; Poplar River adjacent to Turtle Lake; Buffalo River outlet of Buffalo Lake; Buffalo River at Muskado; 2 rivers in Lancester; 2 rivers in Hallock; 2 rivers in Bronson; Roseau River, Malung township; Roseau River, Blooming Valley; Wild Rice River near Hickson; Wild Rice River, Sergeant County; Wild Rice River near Mantador; Wild Rice River near Calchutt; Wild Rice River near Christine; creek near Mooreton; Wild Rice River near Wyndmere; Wild Rice River near Cayuga; Sheyenne River, Richland County; Sheyenne River, Cass County; Baldhill Creek, Griggs County; Maple River, Cass County; Sheyenne River, Barnes County; Maple River, Barnes County; Sheyenne River, Cass or Richland County; Sheyenne River, Cass County; Sheyenne River, Ransom County; Maple River, Cass or Ransom County; Turtle River, Grand Forks County; Goose River, Traill County; creek, Cavalier County; Forest River, middle branch, Walsh County; Forest River, Walsh County; creek, Grand Forks County; Elm River, Traill County; creek, Grand Forks County; Coll Creek, Grand Forks County; Marshall County (3).

13 small dams on Wild Rice, Sheyenne, Goose Pembina Rivers in North Dakota; on Red, Snake, Roseau Rivers in Minnesota; and Marshall County in South Dakota, have been completed or are under construction as follows:

2 rivers in Hallock, 2 rivers in Bronson, River, Malung Township.; Wild Rice River near Hickson; Wild Rice River near Mantador; Wild Rice River near Calchutt; Wild Rice River near Christine; Wild Rice Creek near Mooreton; Wild Rice River near Cayuga; Sheyenne River Richland County; Goose-Pembina Turtle River, Grand Forks County; Goose-Pembina Creek, Grand Forks County.

Water supply projects:

Water supply and water treatment plants in 133 municipalities ---------- 2,600,000.00

Abercrombie, Alice, Amenia, Aneta, Anseim, Ardoch and Ayr, N. Dak.; Bagley, Barnesville, and Battle Lake, Minn.; Blahon, N. Dak.; Blackduck, Minn.; Blanchard and Bowesmont, N. Dak.; Breckenridge, Minn.; Buffalo, Buttzville and Buxton, N. Dak.; Callaway and Campbell, Minn.; Casselton, Cayuga, Cavalier, Chaffee, Christine, Clifford, Cooperstown, Colgate, and Conway, N. Dak.; Crookston, Minn.; Crystal, Cummings and Dazey, N. Dak.; Detroit Lakes (1) and Dunnelly, Minn.; Drayton, N. Dak.; Dumont, Minn.; Dwight, N. Dak.; East Grand Forks, Minn.; Eckelson, N. Dak.; Elbow Lake, Minn.; Elliott, Enderlin, Englevale, Erie, and Fairdale, N. Dak.; Fergus Falls (1) and Fertile, Minn.; Fingal, Finley, Fordville, and Forest River, N. Dak.; Frazee, Minn.; Galesburg, Glasston, Grafton, and Great Bend, N. Dak.; Hancock and Halstad, Minn.; Hamar, Hamberg, Hamilton, Hannaford, Hansboro, Hastings, Heimdal, and Hunter, Kathryn, and Kindred, N. Dak.; Lake Park, Minn.; Langdon, Lankin, Lisbon, Litchville, Maddock, Manvel, Martin, Matton, McCanna, McLeod, McHenry, Mekinock, Michigan, and Minto, N. Dak.; Moorhead, Minn. (1); Mooreton, Mountain, and Neche, N. Dak.; New York Mills, Minn.; Niagara and Nome, N. Dak.; Northome, Minn.; Northwood, N. Dak.; Oklee, Minn.; Oriska, Orr, Page, Park River, and Pekin, N. Dak.; Pelican Rapids, Minn.; Pembina, Pillsbury, Pisek, and Portland, N. Dak,; Red Lake Falls, Minn.; Reynolds, N. Dak.; Roseau, Minn.; Rutland, Sanborn, Sharon, Sheldon, Sheyenne, and St. Thomas, N. Dak.; Thief River Falls, Minn.; Thompson, Tolna, and Tower City, N. Dak.; Twin Valley, Minn.; Valley City, Wahpeton, and Walum, N. Dak.; Warren, Minn.; Wellsburg, Wettman, and Wheatland, N. Dak.; Wheaton, Minn.; Wimbledon, N. Dak.; Wolverton, Minn.; Wyndmere, N. Dak.

Water supply and water treatment plants have been completed or are under construction in 12 municipalities as follows: Argyle (1), Bagley (1), Detroit Lakes (1), Fergus Falls (2), Fosston (1), Halstad (1), Hawley (1), McIntosh (1), Moorhead (1), Northome (1), Perham (1), and Thief River Falls (1).

Pollution projects:

Sewer systems and sewage treatment plants in 61 municipalities ---------- $2,600,000.00

Abercrombie, N. Dak.; Ada, Argyle, Bagley, Barnesville, Battle Lake, Blackduck, Breckenridge, and Callaway, Minn.; Casselton and Cavalier, N. Dak.; Crookston (3), Detroit Lakes (2), Dilworth, and Donnelly, Minn.; Drayton, N. Dak.; East Grand Forks and Elbow Lake, Minn.; Enderlin and Fairmont, N. Dak.; Fergus Falls (3), Fertile (1), Fosston (1), Frazee, and Gracevllle, Minn.; Grafton, N. Dak.; Hallock and Halstad, Minn.; Harvey, N. Dak.; Hawley and Herman, Minn.; Hillsboro, N. Dak.; Kelliher, Minn.; Kindred, N. Dak.; Lake Park, Minn.; Larlmore and Maddock, N. Dak.; Mahnomen, Minn.; Mayville, Milnor, Minto, and Neche, N. Dak.; Northome, Minn.; Park River, N. Dak.; Pelican Rapids, Minn.; Pembina, N. Dak.; Perham, Minn. (1); Portland, N. Dak.; Red Lake Falls and Roseau, Minn.; Sheyenne and St. Thomas, N. Dak.; Thief River Falls and Twin Valley, Minn.; Wahpeton and Walhalla, N. Dak.; Warren, Minn.; West Fargo and Wyndmere, N. Dak.; Wolverton, Minn.; Valley City, N. Dak.

Sewer systems and sewage treatment plants have been completed or are under construction in 12 municipalities as follows: Callaway (1), Crookston (3), Detroit Lakes (2), Fergus Falls (6), Fertile (1), Fosston (1), Hawley (1), Moorhead (1), New York Mills (2), Pelican Rapids (2), Perham (4), and Wheaton (2).

GROUP B, FOR DEFERRED CONSTRUCTION

General—Wildlife:

49 small dams and reservoirs for water conservation, recreation and game refuges listed in class C-- 200,000.00

Red Lake subbasin; Richland, Richland, Cass, Sargent, Barnes, Barnes, Barnes, Barnes, Barnes, Barnes, Pierce, Pierce, Grand Forks, Traill, Grand Forks, Grand Forks, Grand Forks, Walsh, Cavalier, Cavalier, Towner, Traill, Traill, Walsh, Walsh, Cavalier, Walsh, Grand Forks, Grand Forks, Traill, Traill, Grand Forks, Grand Forks, Cavalier, Walsh, Cavalier Counties; south branch in Cavalier County; Grand Forks County; Tongue River in Pembina County; Forest River in Grand Forks County; creek in Walsh County; creek in Walsh County; Elm River in Steele County; Goose River, middle branch in Steele County; Goose River, south branch in Steele County; Elm River in Traill County, drainage ditch in Cavalier County; Rush Lake outlet in Cavalier County.

Revised Summary of the Red River of the North Project List—Continued

Details of Major Construction Projects—Continued

GROUP B. FOR DEFERRED CONSTRUCTION—Continued

18 small dams and reservoirs for water conservation, recreation, and game refuges have been completed or are under construction as follows: Barnes County (7), Cass County (1), Cavalier County (2), Grand Forks County (1), Griggs County (2), Richland County (2), Pierce County (1), and Sargent County (2).

General—Wildlife:

31 municipal water-supply and treatment plants and sewerage and sewer treatment plants listed in class C---------- $700,000.00

Municipal water supply and treatment:

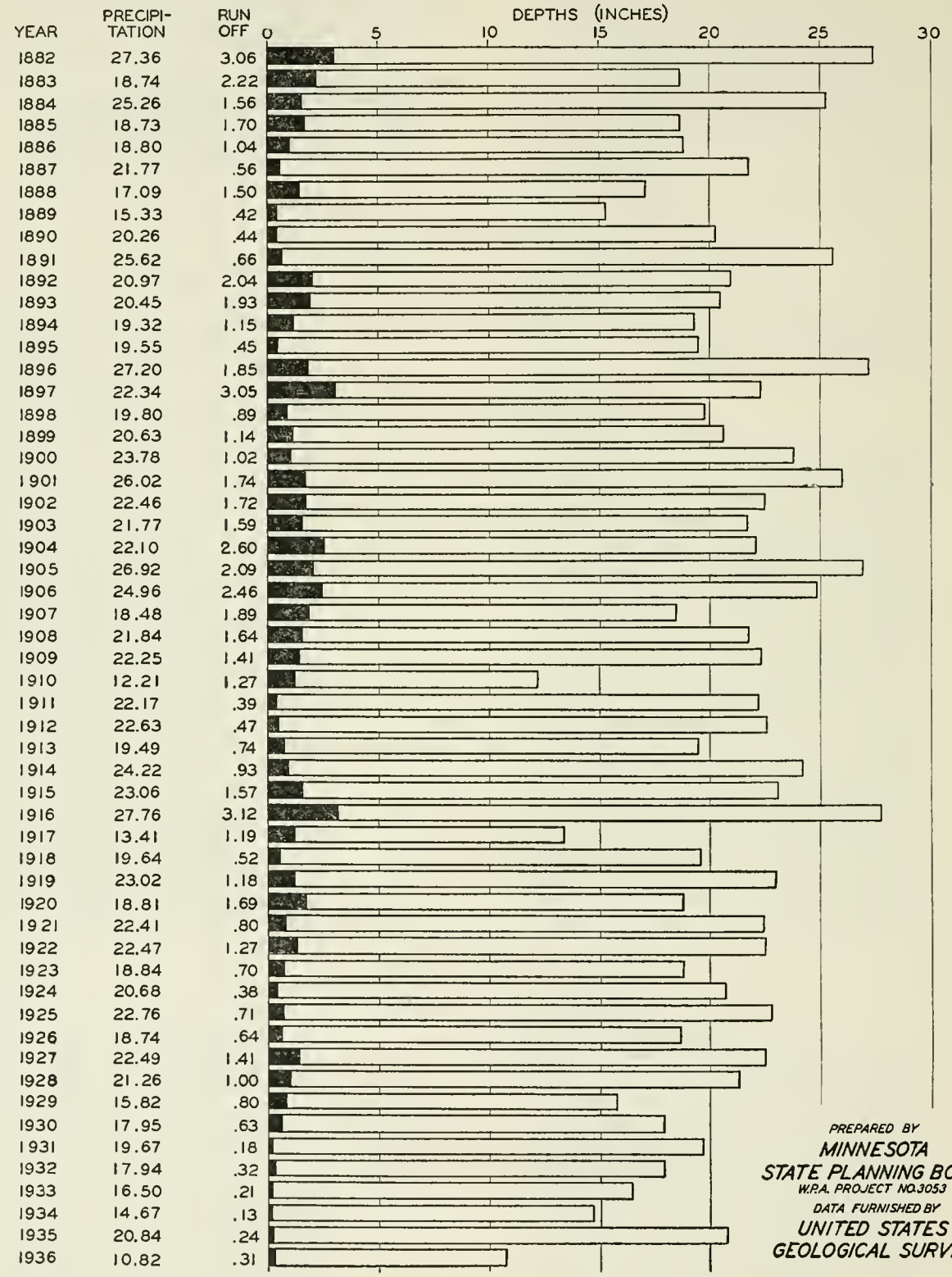
Havana, Lidgerwood, Barney, Colfax, Wallcott, Brampton, Cogswell, Delamere, Forman, Gwinner, and Milnor.

Sewerage and sewerage treatment plants:

Hankinson, Lidgerwood, Cogswell, Forman, Gwinner, McVille, Wimbledon, Litchville, Tower City, Cooperstown, Finley, Hope, Hunter, Page, Landom, Aneta, Michigan, Northwood, Hatton, and Buxton.

PRECIPITATION AND RUN-OFF

RED RIVER BASIN ABOVE GRAND FORKS N.D.



YEAR	PRECIPITATION	RUN OFF
1882	27.36	3.06
1883	18.74	2.22
1884	25.26	1.56
1885	18.73	1.70
1886	18.80	1.04
1887	21.77	.56
1888	17.09	1.50
1889	15.33	.42
1890	20.26	.44
1891	25.62	.66
1892	20.97	2.04
1893	20.45	1.93
1894	19.32	1.15
1895	19.55	.45
1896	27.20	1.85
1897	22.34	3.05
1898	19.80	.89
1899	20.63	1.14
1900	23.78	1.02
1901	26.02	1.74
1902	22.46	1.72
1903	21.77	1.59
1904	22.10	2.60
1905	26.92	2.09
1906	24.96	2.46
1907	18.48	1.89
1908	21.84	1.64
1909	22.25	1.41
1910	12.21	1.27
1911	22.17	.39
1912	22.63	.47
1913	19.49	.74
1914	24.22	.93
1915	23.06	1.57
1916	27.76	3.12
1917	13.41	1.19
1918	19.64	.52
1919	23.02	1.18
1920	18.81	1.69
1921	22.41	.80
1922	22.47	1.27
1923	18.84	.70
1924	20.68	.38
1925	22.76	.71
1926	18.74	.64
1927	22.49	1.41
1928	21.26	1.00
1929	15.82	.80
1930	17.95	.63
1931	19.67	.18
1932	17.94	.32
1933	16.50	.21
1934	14.67	.13
1935	20.84	.24
1936	10.82	.31

PREPARED BY
MINNESOTA
STATE PLANNING BOARD
W.P.A. PROJECT NO.3053
DATA FURNISHED BY
UNITED STATES
GEOLOGICAL SURVEY

L.J.E. 3-37

APPENDICES

APPENDIX A—WATER CONSERVATION AND FLOOD PREVENTION[1]

Human activities are so dependent upon water that periods of drought quickly emphasize the need for water conservation. Similarly, flood periods focus attention upon the havoc wrought by an excess of water. In the presence of one extreme condition the other is quickly forgotten. Long-range planning demands consideration of both extremes, and also of the normal condition. Such planning should be based upon the best possible interpretation of all available hydrologic data. Although general information respecting floods and drought has come down through the ages, long-time records of rainfall, run-off, temperature, relative humidity, wind velocity, and evaporation are still all too meager. Rainfall and temperature have been measured for more than a hundred years at the principal Weather Bureau stations in the United States, but comparatively few accurate records of other phenomena extend back even 50 years. The possible extremes are unknown today. For the present it is necessary to assume that the future will bring alternating floods and droughts much as the past has done.

This generation finds itself confronted with the task of planning hydraulic works that are to endure a century or more on the basis of hydrological observations covering only a few decades. Has man's occupancy of the earth affected rainfall, evaporation, and run-off, or are the floods of the 1880's and the droughts of the 1930's merely natural variations of hydrologic phenomena that will show still greater extremes within the life of the structures we are now building? In the absence of sufficient basic data, we must plan with moderation and not endeavor to change nature's regime too drastically lest future generations charge us with shortsightedness.

General Hydrologic Data

According to Water Supply Paper No. 772, the average precipitation in the basin of the Red River of the North at Grand Forks from 1882 to 1934 was 21 inches. In 1882 there was only one rainfall station to about 8,500 square miles. In 1930 there was one to about every 910 square miles. The least recorded precipitation occurred in 1910, but this year was preceded and followed by years of more than normal precipitation. Consequently the drought was less severe.

From 1929 to 1935, the precipitation was continually below normal, resulting in unprecedented drought conditions. Although there were spring freshets during these years, the flow at Fargo was zero during five periods aggregating 14 months. The flow at Grand Forks fell below 100 cubic feet per second during 1932, 1933, 1934, and 1935, aggregating 23 months. Many lakes in the basin fell to levels below the elevation of zero outflow. Wells ceased flowing and had to be abandoned or deepened. The ground-water table lowered. An extreme shortage of water for even the most urgent domestic and sanitary needs existed in the basin. Surface supplies vanished in several localities, and no potable underground supplies were available. Water storage and stream regulation are essential means for meeting such emergencies.

According to Water Supply Paper No. 772, the average run-off at Grand Forks from 1882 to 1934 was only 1.25 inches, and evaporation and transpiration losses averaged 19.67 inches, assuming no progressive change in ground-water storage during that period. This, however, appears doubtful. The indications are that ground water reserves were depleted during this period. If so, the evaporation and transpiration loss was still nearer 20 inches.

For the last 7 years, 1929 to 1935, the average run-off at Grand Forks was only 0.36 inch a year. This represents an extremely small amount of water available for storage and stream regulation.

Hydrograph of Flow

The following diagram is a hydrograph of monthly mean discharge of the Red River of the North at Fargo and at Grand Forks. It shows graphically and impressively the severity of the recent drought.

During the 7 years of drought, the rainfall was very unequally distributed over this basin. For that reason, storage projects located in different portions of the basin will be more effective than a consideration of merely the average run-off would indicate.

During the spring freshets of 1929 and 1930, there was a good flow at Fargo and Grand Forks. During 1931 and 1932, the spring flow at Fargo was considerably less than during the previous years. At Grand Forks the flow in the spring of 1932 was much greater than in 1931. The crucial drought period, from the viewpoint of moderate-sized storage reservoirs began after the spring run-off in 1932, and has not yet ended from the viewpoint of being able to fill all the reservoirs again if they had been in existence. Since the spring of 1935, however, there has been an increase in the available supply. Rainfall has been near normal

[1] By Adolph F. Meyer, consulting hydraulic engineer. In the original report this paper was designated as appendix 2.

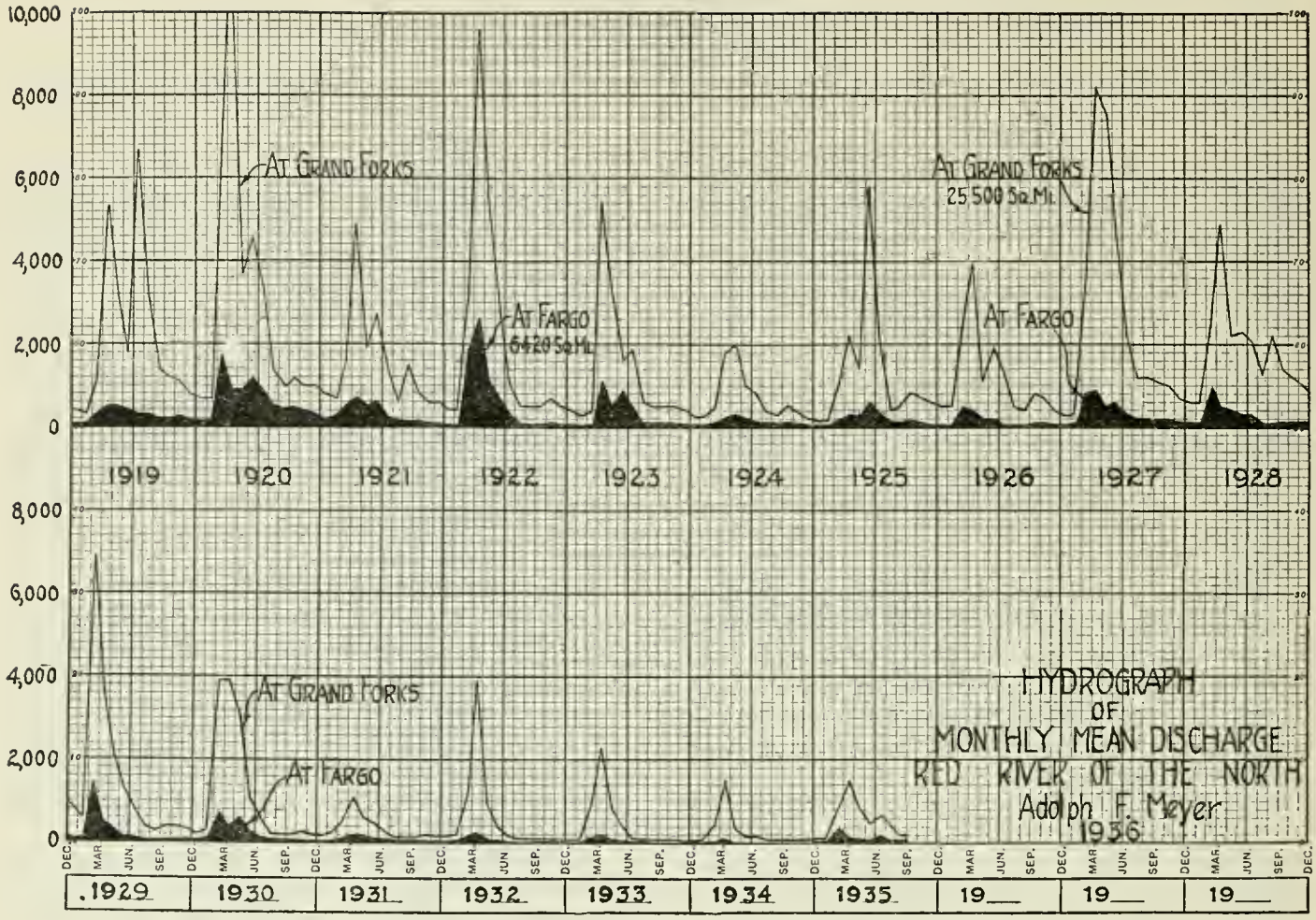


FIGURE 9

and evaporation has been much less than during previous years.

After the spring run-off in 1932, most of the lakes in the basin were apparently at fairly high levels. The Red Lakes are an exception. These lakes fell continuously from the fall of 1928 until the present date, except for temporary rises during May and June of each year. In April 1932, the flow at High Landing, below the outlet, represented only 0.04 inch in depth on the drainage basin, but outflow was prevented by a dam built in 1931.

The April 1932 Freshets

Because of the importance of conditions prevailing in the spring of 1932, which was the beginning of the crucial drought period for most of the basin, a detailed study has been made of precipitation and run-off during the fall, winter, and spring.

The following maps give:

1. The fall precipitation in the basin, September 1 to October 31, 1931.

2. The winter and early spring precipitation in the basin, November 1, 1931, to April 10, 1932.

3. The peak discharge of the main stream and its tributaries during the April freshet and the average discharge for April, in cubic feet per second per square mile.

The fall rains were heavy over the lower portion of the basin, reaching 7 inches at Hallock. The average over the upper basin was 4 inches, reducing to 3 inches over Lake Traverse.

The winter precipitation and the April rains leading up to the freshet crests about April 10 were excessive over the northeast portion of the basin and along the eastern divide. The maximum was reached in the Crow Wing Basin just east of the divide.

As the result of heavy fall and winter precipitation, there was heavy run-off from the drainage areas in the northeast portion of the basin, resulting in a flow at Grand Forks equal to about 25 percent of the maximum recorded flood.

The yield shown for the Otter Tail Basin is very small. However, there was some run-off during February and March, and much water was stored in Otter Tail Lake. When these facts are taken into consideration, the yield of the Otter Tail Basin is comparable

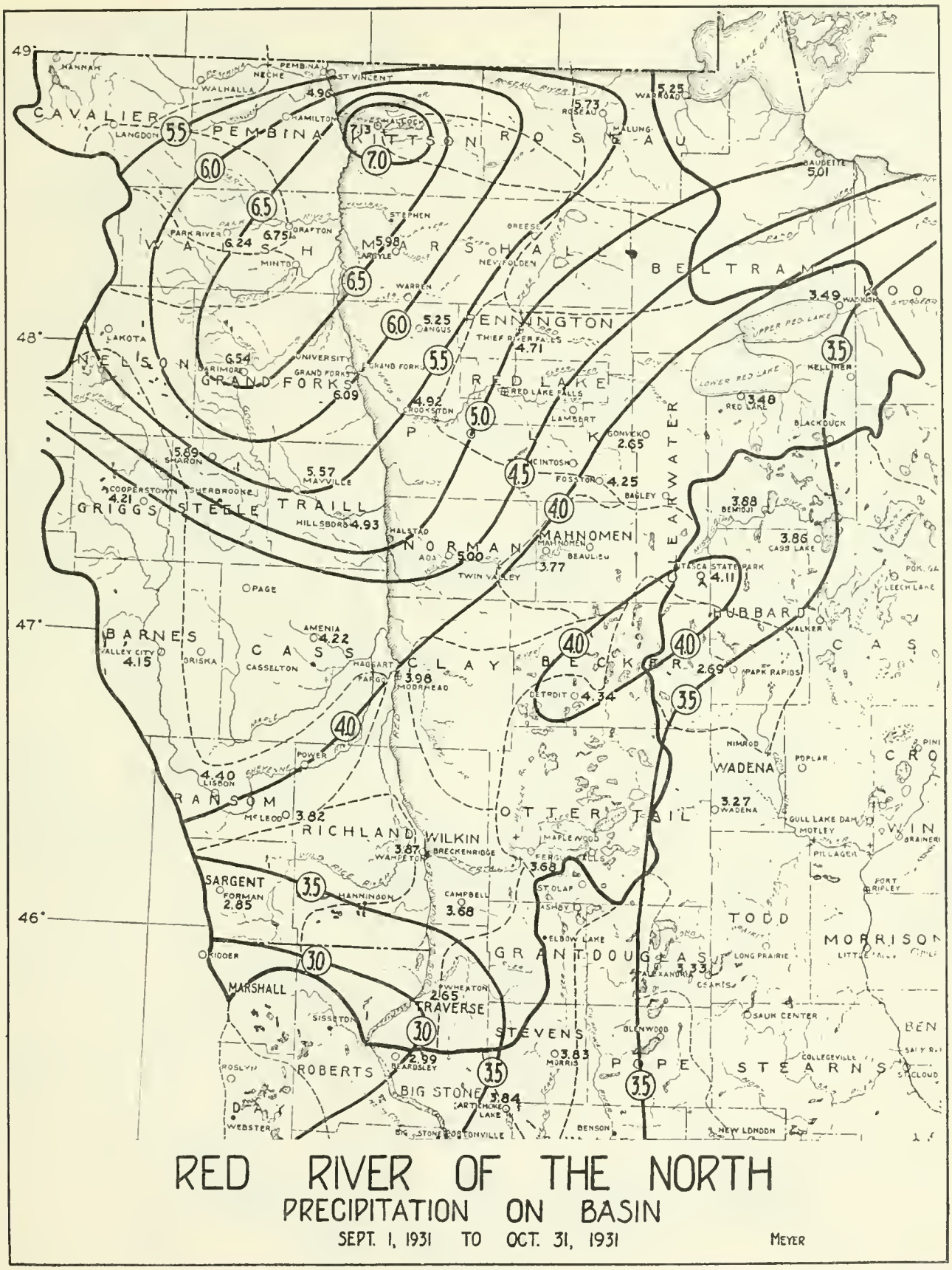

RED RIVER OF THE NORTH
PRECIPITATION ON BASIN
SEPT. 1, 1931 TO OCT. 31, 1931
MEYER
CAVALIER
PEMBINA
RITTSON
ROSEAU
WARROAD
LAKE OF THE WOODS
WALSH
MARSHALL
BELTRAMI
KOOCHICHING
PENNINGTON
RED LAKE
POLK
NELSON
GRAND FORKS
LAKOTA
LOWER RED LAKE
UPPER RED LAKE
KELLIHER
BLACKDUCK
RED LAKE
LAMBERT
GONVICK
MCINTOSH
FOSSTON
BAGLEY
BEMIDJI
CASS LAKE
LEECH LAKE
TWIN VALLEY
MAHNOMEN
NORMAN
BECKER
CLEARWATER
HUBBARD
WALKER
PARK RAPIDS
DETROIT
TRAIL
GRIGGS
STEELE
HILLSBORO
COOPERSTOWN
SHERBROOKE
MAYVILLE
SHARON
BARNES
VALLEY CITY
CASSELTON
HARWOOD
FARGO
MOORHEAD
CLAY
CASS
PAGE
AMENIA
BRISKA
LISBON
RANSOM
POWER
MCLEOD
RICHLAND
WILKIN
WAHPETON
BRECKENRIDGE
SARGENT
FORMAN
HANKINSON
OTTER TAIL
FERGUS FALLS
MAPLEWOOD
ST OLAF
ASHBY
CAMPBELL
ELBOW LAKE
WADENA
NIMROD
POPLAR
MOTLEY
PILLAGER
GULL LAKE DAM
CROW WING
TODD
MORRISON
LITTLE FALLS
LONG PRAIRIE
ALEXANDRIA
OSAKIS
SAUK CENTER
GLENWOOD
GRANT
DOUGLAS
KIDDER
WHEATON
TRAVERSE
SISSETON
ROSLYN
ROBERTS
STEVENS
MORRIS
POPE
STEARNS
COLLEGEVILLE
SAINT CLOUD
BENSON
NEW LONDON
BIG STONE
ARTICHOKE LAKE
ODESSA
WEBSTER
DAY
BEN
4.96
5.25
5.73
7.13
5.01
6.75
6.24
5.98
3.49
5.25
4.71
6.54
6.09
4.92
3.48
2.65
5.89
5.57
4.25
4.21
4.93
3.88
5.00
3.77
3.86
4.11
4.22
4.15
3.98
4.34
2.69
4.40
3.82
3.87
3.68
3.27
2.85
3.68
3.33
2.65
2.99
3.83
3.84
5.5
6.0
6.5
7.0
5.0
4.5
4.0
3.5
3.0
49°
48°
47°
46°

FIGURE 10

RED RIVER OF THE NORTH
PRECIPITATION ON BASIN
NOV. 1, 1931 TO APR. 10, 1932
MEYER
CAVALIER
PEMBINA
KITTSON
ROSEAU
LAKE OF THE WOODS
WALSH
MARSHALL
BELTRAMI
PENNINGTON
RED LAKE
POLK
NELSON
GRAND FORKS
GRIGGS
STEELE
TRAILL
NORMAN
MAHNOMEN
CLEARWATER
HUBBARD
CASS
BARNES
CLAY
BECKER
OTTER TAIL
WADENA
RANSOM
RICHLAND
WILKIN
SARGENT
GRANT
DOUGLAS
TODD
MORRISON
TRAVERSE
STEVENS
POPE
STEARNS
BENTON
ROBERTS
BIG STONE
SWIFT
KANDIYOHI
MEEKER
WRIGHT
HANNAH
PEMBINA
ST. VINCENT
WALHALLA
HAMILTON
LANGDON
ROSEAU
WARROAD
LAKE OF THE WOODS
BAUDETTE
GRAFTON
PARK RIVER
STEPHEN
ARGYLE
MINTO
BREESE
NEWFOLDEN
WARREN
KARLSTAD
THIEF RIVER FALLS
ANGUS
WASKISH
KELLIHER
UPPER RED LAKE
LOWER RED LAKE
RED LAKE FALLS
RED LAKE
CROOKSTON
LAMBERT
GONVICK
BLACKDUCK
MCINTOSH
FOSSTON
BAGLEY
DEMIDJI
CASS LAKE
ITASCA STATE PARK
LEECH LAKE
LARIMORE
UNIVERSITY
E GRAND FORKS
GRAND FORKS
SHARON
COOPERSTOWN
SHERBROOKE
MAYVILLE
NILLSBORO
HALSTAD
ADA
TWIN VALLEY
BEAULIEU
OPACE
ARTHUR
VALLEY CITY
ORISKA
CASSELTON
HAGGART
FARGO
MOORHEAD
DETROIT
WALKER
PARK RAPIDS
NIMROD
POPLAR
WADENA
GULL LAKE DAM
MOTLEY
BRAINERD
PILLAGER
FORT RIPLEY
LISBON
POWER
MCLEOD
WAHPETON
BRECKENRIDGE
MAPLEWOOD
FERGUS FALLS
WANAMINGO
HANKINSON
FORMAN
CAMPBELL
ST. OLAF
ASHBY
ELBOW LAKE
LONG PRAIRIE
ALEXANDRIA
OSAKIS
LITTLE FALLS
SAUK CENTER
GLENWOOD
MORRIS
COLLEGEVILLE
ST. CLOUD
SAUK RAPIDS
SISSETON
ROSLYN
BEARDSLEY
ARTICHOKE LAKE
BIG STONE
ORTONVILLE
BENSON
NEW LONDON
WEBSTER
DAY
4.38
3.35
4.99
5.04
3.15
3.39
4.56
5.73
4.79
4.41
4.60
3.32
4.13
5.18
5.65
3.87
2.22
2.17
7.50
8.10
5.77
5.61
4.45
3.39
6.12
3.18
3.44
6.13
6.92
4.99
3.00
2.55
3.33
6.16
1.99
5.46
4.00
4.55
6.15
3.48
5.40

FIGURE 11

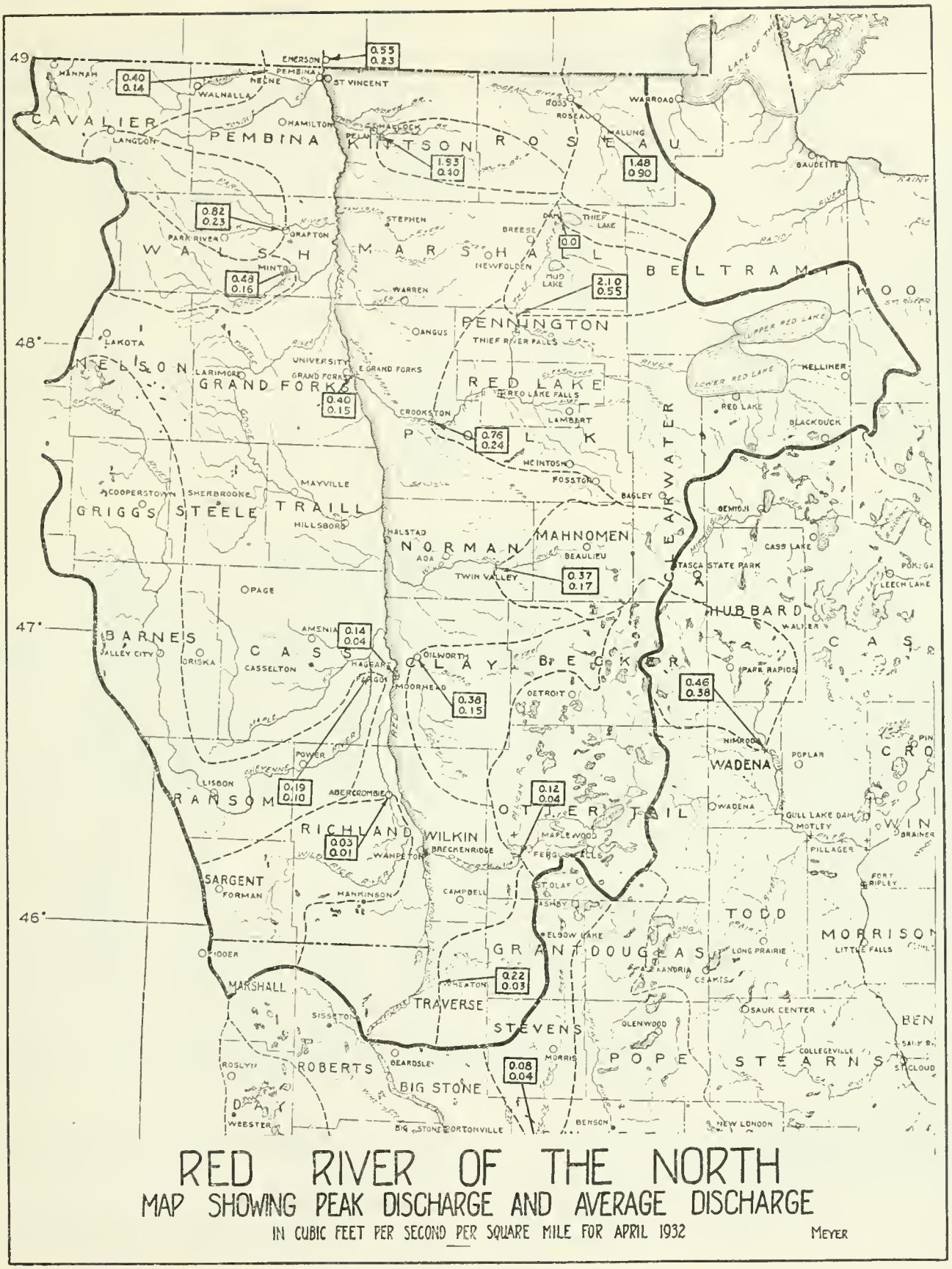

RED RIVER OF THE NORTH
MAP SHOWING PEAK DISCHARGE AND AVERAGE DISCHARGE
IN CUBIC FEET PER SECOND PER SQUARE MILE FOR APRIL 1932
MEYER
49
48°
47°
46°
CAVALIER
PEMBINA
KITTSON
ROSEAU
WALSH
MARSHALL
BELTRAMI
LAKE OF THE WOODS
NELSON
GRAND FORKS
PENNINGTON
RED LAKE
POLK
CLEARWATER
GRIGGS
STEELE
TRAILL
NORMAN
MAHNOMEN
BECKER
HUBBARD
CASS
BARNES
CLAY
OTTER TAIL
WADENA
CROW WING
RANSOM
RICHLAND
WILKIN
SARGENT
GRANT
DOUGLAS
TODD
MORRISON
MARSHALL
TRAVERSE
STEVENS
POPE
STEARNS
BENTON
ROBERTS
BIG STONE
0.55 0.23
0.40 0.14
1.93 0.40
1.48 0.90
0.82 0.23
0.0
0.48 0.16
2.10 0.55
0.40 0.15
0.76 0.24
0.37 0.17
0.14 0.04
0.38 0.15
0.46 0.38
0.19 0.10
0.12 0.04
0.03 0.01
0.22 0.03
0.08 0.04

FIGURE 12

Red River of the North—Precipitation causing April freshets, 1932

Station	September to October	November to Apr. 10	September to Apr. 10	Station	September to October	November to Apr. 10	September to Apr. 10
Minnesota				*Minnesota*—Continued			
Ada	5.09	4.45	9.54	Roseau	5.73	5.04	10.77
Alexandria	3.33	4.00	7.33	Thief River Falls	4.71	5.73	10.44
Angus	5.25	4.56	9.81	Wadena	3.27	----------	----------
Argyle	5.98	3.11	9.09	Warroad	5.25	4.99	10.24
Artichoke	3.84	3.40	7.24	Washkish	3.49	4.79	8.28
Baudette	5.01	9.15	14.16	Wheaton	2.65	4.55	7.20
Beardsley	2.99	3.48	6.47				
Bemidji	3.88	8.10	11.98	*North Dokota*			
Campbell	3.68	5.46	9.14	Amenia	4.22	3.18	7.40
Cass Lake	3.86	5.71	9.57	Cooperstown	4.21	2.22	6.43
Crookston	4.92	3.32	8.24	Forman	2.85	1.99	4.84
Detroit Lakes	4.34	4.99	9.33	Grafton	6.75	3.39	10.14
Fergus Falls	3.68	6.16	9.84	Grand Forks	6.09	4.60	10.69
Fosston	4.25	7.50	11.75	Hillsboro	4.93	5.61	10.54
Gonvick	2.55	5.65	8.20	Larimore	6.54	4.41	10.95
Hallock	7.13	4.38	11.51	Lisbon	4.40	3.08	7.48
Itasca	4.11	6.12	10.23	Mayville	5.57	2.17	7.74
Mahnomen	3.77	3.39	7.16	McLeod	3.82	2.55	6.37
Moorhead	3.98	4.13	8.11	Park River	6.24	1.77	8.01
Morris	3.83	6.15	9.98	Pembina	4.96	3.35	8.31
Park Rapids	2.69	8.92	11.61	Sharon	5.89	3.87	9.76
Redby	3.48	5.18	8.66	Valley City	4.15	3.44	7.59
Red Lake Falls	----------	4.13	----------	Wahpeton	3.87	3.33	7.20

Red River of the north—Freshets, April 1932

Name of basin	Area, square miles	Peak discharge			Average discharge		Run-off in acre-feet	
		Date, April	Cubic feet per second	Cubic feet per second per square mile	Cubic feet per second	Cubic feet per second per square mile	April	October 1931 to September 1932
Red at Emerson	34,600	15	18,900	0.55	7,810	0.23	465,000	772,000
Red at Grand Forks	25,500	10	10,200	.40	3,930	.15	234,000	452,000
Red at Fargo	6,420	11	868	.14	232	.04	13,800	38,100
Otter Tail below Pelican	1,950	10	242	.12	82	.04	4,860	30,600
Crow Wing at Nimrod	1,010	9	464	.46	386	.38	23,600	[1] 165,000
Wild Rice at Twin Valley	805	9	295	.37	138	.17	8,210	[1] 27,800
Buffalo near Dilworth	825	12	311	.38	123	.15	7,320	[1] 21,700
Mustinka above Wheaton	776	7	173	.22	26	.03	1,530	[1] 4,312
Pomme de Terre at Appleton	950	7	72	.08	41	.04	2,460	[1] 11,200
Wild Rice at Abercromble	1,070	13	28	.03	14	.01	723	[1] 1,650
Sheyenne at West Fargo	5,560	13	1,040	.19	551	.10	32,800	78,400
Red Lake River at Crookston	5,320	9	4,070	[2].76	1,300	[2].24	77,400	138,000
Thief near Thief River Falls	1,010	8	1,310	[3] 1.30	342	[3].34	20,400	22,000
Roseau at Ross	1,030	12-13	1,520	1.47	928	.90	55,200	115,000
Two Rivers at Pelan (south branch)	590	9	1,140	1.93	239	.40	14,200	18,900
Forest at Minto	550	9	265	.48	91	.16	5,430	[1] 10,500
Park at Grafton	670	8	550	.82	155	.23	9,220	[1] 13,200
Pembina at Neche	2,960	9	1,170	.40	423	.14	25,200	44,100

[1] Partly estimated.

[2] When the Thief Lake area, from which there was no discharge, is deducted, these figures become 2.10 and 0.55, respectively.

[3] When both the Thief Lake area, from which there was no discharge, and the Red Lake area, from which there was practically no discharge, are deducted, these figures become 1.41 and 0.44, respectively.

with the yield of the Crow Wing, Wild Rice, and Buffalo River Basins adjoining.

The yield of the Red Lake Basin above High Landing was only 0.04 inch in April 1932, but the Red Lakes rose at least 0.5 foot during the month. This represents more than 1 inch run-off from the tributary drainage area. The Thief River yielded 0.55 inch and the Roseau, 0.90 inch.

The run-off above Grand Forks during April 1932 was nearly four times as much per square mile as it was at Fargo.

Reservoirs in different portions of the basin will realize the maximum storage benefits from such variations in run-off as those which were recorded during the spring of 1932.

The table on page 46 summarizes the most important data relating to the April 1932 freshets. The outstanding facts are the extremely high discharges of the streams in the northern portion of the basin. The reason for this is clearly shown by the maps of fall and winter precipitation. Notwithstanding the heavy run-off into the Red Lakes, these lakes did not recover to the level of the previous spring.

The contribution of the Otter Tail, the Dakota Wild Rice, and the Sheyenne Rivers to the flow at Grand Forks in April 1932 was extremely small. Lake Traverse contributed nothing; nor could much run-off have been expected, because both fall rains and winter precipitation were the lowest in the entire basin.

Thief and Mud Lakes Projects

Although there was heavy run-off from the Thief River Basin in April 1932 the area of 387 square miles above Thief Lake contributed nothing and has continued to contribute no flow whatsoever to the present date. A solid overfall spillway dam was built in the outlet in 1931, and the lake is still about 4 feet below the crest of the dam. It has been slowly rising with spring and summer fluctuations. After the lake is full, there will be some outflow in wet years.

Another dam is contemplated at the outlet of Mud Lake, with the Thief River diverted permanently into the lake. Both of these lakes are of substantial size. They have been estimated at about 7,000 acres each, although the area given for Mud Lake by the Department of Drainage and Waters is much less. Both lakes will be only about 8 feet deep in their central area. Evaporation losses will be heavy, but there are indications of substantial percolation. These projects will not contribute to the low-water flow at Crookston during extreme drought periods unless sluices are provided for releasing some water after the lakes have fallen below the level of the crest of the dams at the outlets. The ground-water movement is probably toward the north, away from Crookston and Grand Forks.

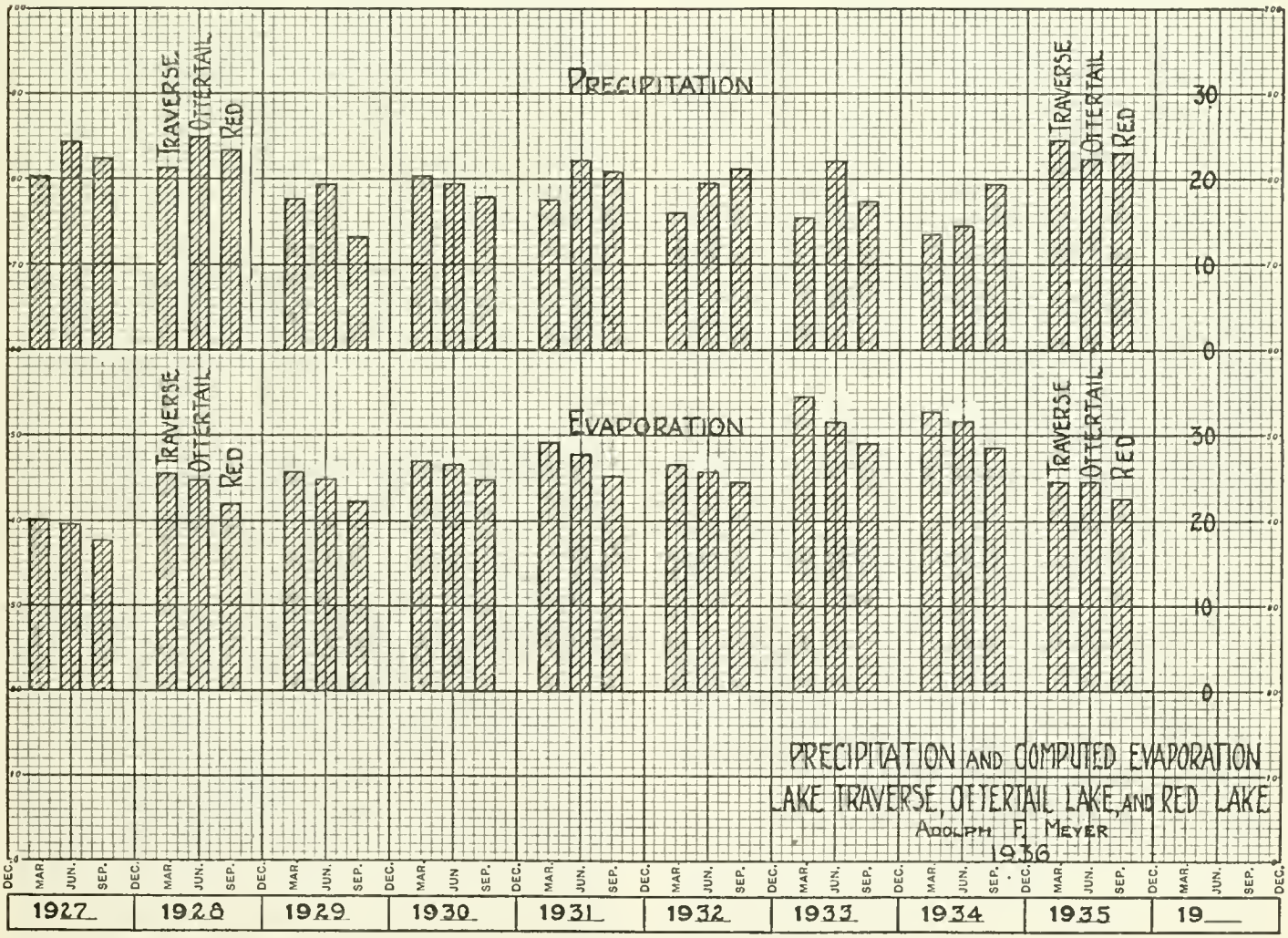


FIGURE 13

Relative Value of Several Lakes

The diagram on page 47 gives a graphical comparison for 9 years between the computed evaporation from Lake Traverse, Otter Tail Lake, and Red Lake, using the relative humidity and wind velocity observed at Moorhead, and a coefficient of 10 in the Meyer evaporation formula as applied to all three lakes. Since it was necessary to use the same relative humidity and wind velocity, the only change in computed evaporation from these three lakes is due to changes in temperature.

The lower evaporation from Red Lake, even though the higher Red Lake Falls temperatures were used, is striking. These temperatures are appreciably higher in spring and lower in fall than the Redby temperatures on the southeast side of the lake. Usually the April temperature is 2° or 3° higher and the September and October temperature is about 1° lower than the Redby temperature. If the water temperature of Red Lake itself had been available, this would have shown still greater lag.

The precipitation at Redby averaged 1.6 inches greater than that at Red Lake Falls.

A comparison of Mayville, N. Dak., and Mahnomen, Minn., precipitation does not show a corresponding difference even though the two stations are in relatively similar locations, except with respect to the large water area of Red Lake. Mayville temperature is uniformly higher than Mahnomen temperature.

The total evaporation from Lake Traverse during the 9-year period was 246 inches; the rainfall was 168 inches, making a net loss of 78 inches in depth on the lake, irrespective of run-off from the land area.

The total evaporation from Otter Tail Lake during the period was 236 inches; the rainfall was 189 inches, making a net loss of 47 inches.

The total evaporation from Red Lake during the period was 217 inches; the rainfall was 179 inches, making a net loss of 38 inches.

From the viewpoint of storing water for use at Grand Forks during drought periods, Red Lake possesses a decided advantage over Lake Traverse, and, to some extent, also over Otter Tail Lake. Red Lake should be utilized to the utmost. If fluctuation interferes with the wild rice supply for the Indians, this food need should be met in other ways. It should not be permitted to interfere with the best regulation of Red Lake for domestic and sanitary water needs of cities on the Red River of the North.

Effect of Water Areas on Rainfall

During the last 9 years, which include the drought period, the Otter Tail Basin had the highest rainfalls, and Lake Traverse, the lowest. This may be a fortuitous circumstance, or it may be an indication that the, substantially, 20 percent lake and pond area in the Otter Tail Basin has had some effect on rainfall. The unpublished investigations of Prof. J. C. Jensen, of Nebraska Wesleyan University, made in the Otter Tail Basin in August 1935 indicate that the air on the leeward side of lakes contained about 25 percent more moisture than the air on the windward side at the same time. In some cases, the temperature was as much as 9° lower on the leeward side, and precipitation was higher.

A paper by Professor Jensen, published in the May 1935 bulletin of the American Meteorological Society, shows that there was greater rainfall in the lake region around Watertown, S. Dak., during the summer months of 1934 than in the region to the southwest.

In the same issue, Mr. J. B. Kincer, of the United States Weather Bureau, Washington, D. C., contends that increased lake, pond, and marsh area may get moisture into the air, but that the principal difficulty during drought periods is the failure of "Nature's rain factory" to operate "in a manner to cause sufficient condensation." He further states, "There is nearly always enough moisture present in the atmosphere to produce rain in substantial amounts." To this I take exception. In fact, in the same issue of the bulletin, Prof. C. F. Brooks remarked that, "The smallness of the quantity of water in the air at one time does not seem to be appreciated", and again, "But in Nebraska there are thunderstorms anyway; give them more vapor and they'll rain."

The air is no storehouse for moisture. A few days' evaporation after a heavy rain sends about as much moisture into the air as it can hold in the face of the normally prevailing air currents. Even under the most favorable summer conditions, the amount of rain which "Nature's rain factory" could produce, uniformly distributed over Minnesota, from the moisture contained in the overlying air, is only about half an inch. A relatively small amount of additional evaporation may appreciably affect precipitation.

Minor Projects

Besides the major projects for storage and stream regulation on the basin of the Red River of the North, hereinafter considered, minor storage projects should be encouraged. The primary goal of water conservation projects is the retardation of surface run-off on its way back to the ocean. Surface run-off represents that portion of continental rainfall which is derived from the ocean. If we retard it and cause its repeated evaporation and transpiration, we have the use of it over and over again. Rainfall which is evaporated or transpired really does not represent a loss. It represents the portion of the rainfall which we save to use over and over again. So-called evaporation and trans-

piration losses represent rainfall derived from the land areas. They represent the currency with which we do the business of raising crops. We should keep this currency in circulation. Once it returns to that central bank, the ocean, we have to wait a long time before we get it back. Every farmer can help retard and conserve the run-off and thus turn it into rainfall. "Ponds on every farm" may well be the aim of water conservation. Similarly, fall plowing, check dams, and soil conservation projects all help to retard surface run-off, and thereby increase the currency of rainfall.

Computing Evaporation

Inasmuch as evaporation losses are basic to all conclusions respecting water conservation, a brief discussion of the method here used in computing evaporation may not be amiss.

After much preliminary work had been done using figure 150 of Elements of Hydrology, by Meyer, for determining evaporation from water areas on the basis of monthly mean temperatures, because this method was very rapid, evaporation was computed by means of the Meyer formula, using the monthly wind velocity and relative humidity observed at Moorhead, Minn. This Weather Bureau station is reasonably representative of conditions in the basin.

Figure 150, above referred to, is based upon mean values of relative humidity and wind velocity for each month. The records show that there are pronounced variations from this mean value. These have a tremendous effect upon the evaporation in different years even though the temperature is the same.

The Meyer evaporation formula has been checked against many recorded evaporation measurements in different parts of the country. One of the best checks on any evaporation formula consists of comparing observed hourly evaporation with computed hourly evaporation. Relatively few observations of this type are available. One of the best records is that for Davis, Calif., published in Bulletin 248, Office of Experiment Stations, United States Department of Agriculture. Evaporation was measured from a 28-inch depth, 22-inch diameter, water-jacketed tank set in the soil. This construction caused a pronounced lag in water temperature behind air temperature.

The mean of the maximum and minimum air temperatures on July 12 to 13, when the observations were made, was 1.8 degrees higher than the true mean based on hourly readings.

The mean of the 8 a. m. and 8 p. m. relative humidity observations was 4.6 percent higher than the true mean relative humidity.

It requires the use of a coefficient of 9.2 in the Meyer formula in order to make the observed hourly evaporation agree with the computed hourly evaporation. It requires a coefficient of 11.8 in the Meyer formula applied to the mean daily water temperature, the mean of the maximum and minimum air temperature, and the mean of the 8 a. m. and 8 p. m. relative humidity to make the observed evaporation for the day check the computed evaporation for the day. Considering the type of evaporation tank used, this coefficient is reasonable.

The following table gives the observed hourly evaporation and the hourly evaporation computed by the Meyer formula, using a coefficient of 9.2.

Observed and computed hourly evaporation in inches at Davis, Calif., July 12 to 13, 1910

Hour	Observed evaporation	Computed by Meyer formula	Hour	Observed evaporation	Computed by Meyer formula
	Inch	*Inch*		*Inch*	*Inch*
1 p. m.	0.015	0.015	2 a. m.	.010	.009
2 p. m.	.018	.017	3 a. m.	.008	.008
3 p. m.	.020	.022	4 a. m.	.007	.008
4 p. m.	.025	.024	5 a. m.	.008	.008
5 p. m.	.027	.027	6 a. m.	.007	.007
6 p. m.	.025	.025	7 a. m.	.006	.006
7 p. m.	.021	.025	8 a. m.	.006	.006
8 p. m.	.020	.019	9 a. m.	.008	.006
9 p. m.	.017	.017	10 a. m.	.007	.008
10 p. m.	.014	.013	11 a. m.	.007	.009
11 p. m.	.011	.012	12 a. m.	.008	.010
12 p. m.	.010	.012			
1 a. m.	.011	.010	Total	.322	.323

The hourly evaporation was computed from the observed hourly water temperature, air temperature, relative humidity, and wind velocity.

The mean of the 8 a. m. and 8 p. m. relative humidity was 63 percent. The mean wind velocity was 6.8 miles per hour. The mean of the maximum and minimum air temperature was 72.2 degrees. The mean water temperature for the day was 78.9 degrees. Using a coefficient of 11.8 in the Meyer formula, with the vapor pressure corresponding to the water temperature and the actual vapor pressure in the air, gives a daily evaporation of 0.32 inch.

Meyer evaporation formula

$$E = C(V - v)(1 + W/10)$$

E = Evaporation in inches, depth per month.
C = 10 for large, deep lakes.
C = 15 for very shallow water.
V = Vapor pressure corresponding to estimated water temperatures.
v = Actual vapor pressure in air based on air temperature and relative humidity as observed by Weather Bureau.
W = Wind velocity in miles per hour as observed by Weather Bureau.

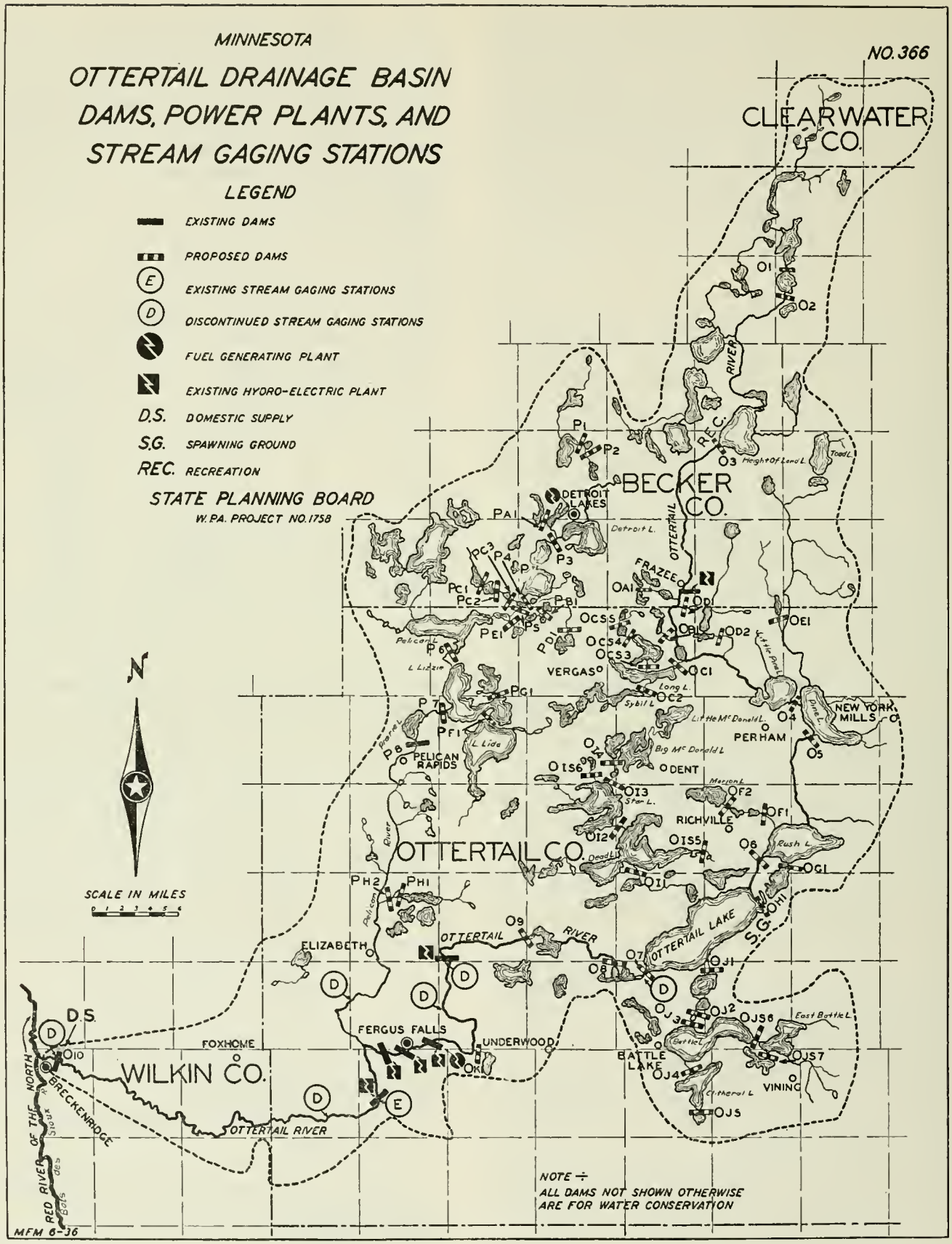

MINNESOTA
OTTERTAIL DRAINAGE BASIN
DAMS, POWER PLANTS, AND
STREAM GAGING STATIONS
NO. 366
LEGEND
EXISTING DAMS
PROPOSED DAMS
EXISTING STREAM GAGING STATIONS
DISCONTINUED STREAM GAGING STATIONS
FUEL GENERATING PLANT
EXISTING HYDRO-ELECTRIC PLANT
D.S. DOMESTIC SUPPLY
S.G. SPAWNING GROUND
REC. RECREATION
STATE PLANNING BOARD
W.P.A. PROJECT NO. 1758
CLEARWATER CO.
BECKER CO.
OTTERTAIL CO.
WILKIN CO.
DETROIT LAKES
FRAZEE
VERGAS
PELICAN RAPIDS
NEW YORK MILLS
PERHAM
DENT
RICHVILLE
ELIZABETH
FERGUS FALLS
FOXHOME
UNDERWOOD
BATTLE LAKE
VINING
OTTERTAIL RIVER
OTTERTAIL LAKE
RED RIVER OF THE NORTH
BRECKENRIDGE
Detroit L.
Pelican L.
L. Lizzie
Long L.
Sybil L.
Lt. Mc Donald L.
Big Mc Donald L.
Star L.
Dead L.
Rush L.
East Battle L.
Cormorant L.
Height Of Land L.
Toad L.
SCALE IN MILES
0 1 2 3 4 5 6
N
NOTE :-
ALL DAMS NOT SHOWN OTHERWISE
ARE FOR WATER CONSERVATION
MFM 6-36

FIGURE 14

The Otter Tail Basin

Basin Characteristics

The Otter Tail drainage basin is one of the best naturally regulated basins in Minnesota. The following 36-year hydrograph of stream flow shows this, and also emphasizes the last 5 years of unprecedented drought.

Of the entire drainage area of 1,920 square miles, 14.5 percent consists of lake surface and 6.25 percent of swamp and marsh surface. Four hundred and six meandered lakes and seven hundred and one nonmeandered lakes were measured by the Department of Drainage and Waters on the best available maps. Natural lake regulation is here found at its best. Lakes of many sizes are scattered throughout the drainage basin, and the largest of these—namely, Otter Tail—is found in the lower part of the basin. A normal year's runoff from the tributary drainage basin represents only 2 to 3 feet depth on Otter Tail Lake. The Otter Tail River has no real floods. The maximum observed flow is less than 1 cubic foot per second per square mile of drainage basin.

The upper portion of the Otter Tail Basin is wooded. Much of the lower portion is under cultivation. Considerable timber and brush, however, is found scattered throughout the lower basin.

The topography of the basin is distinctly rolling. One outstanding feature shown on the following profile is the existence of two irregular plateaus with a rapid drop in elevation between them, from the vicinity of Height of Land Lake to Detroit Lakes. According to the available maps, a considerable area west of Height of Land Lake and northeast of Detroit Lakes has no well-defined outlet. The run-off into the lakes of this area is apparently disposed of by evaporation and percolation to ground water. There is a fall of about 120 feet in 6 miles from this area to Detroit Lakes. Unquestionably, Detroit Lakes, which show a very small fluctuation in level, are fed largely by ground water from the northeast and north.

After dropping from the upper plateau region to the level of Detroit Lakes and the lakes near Frazee, the surface water in both the Pelican and the Otter Tail valleys flows slowly from lake to lake on another

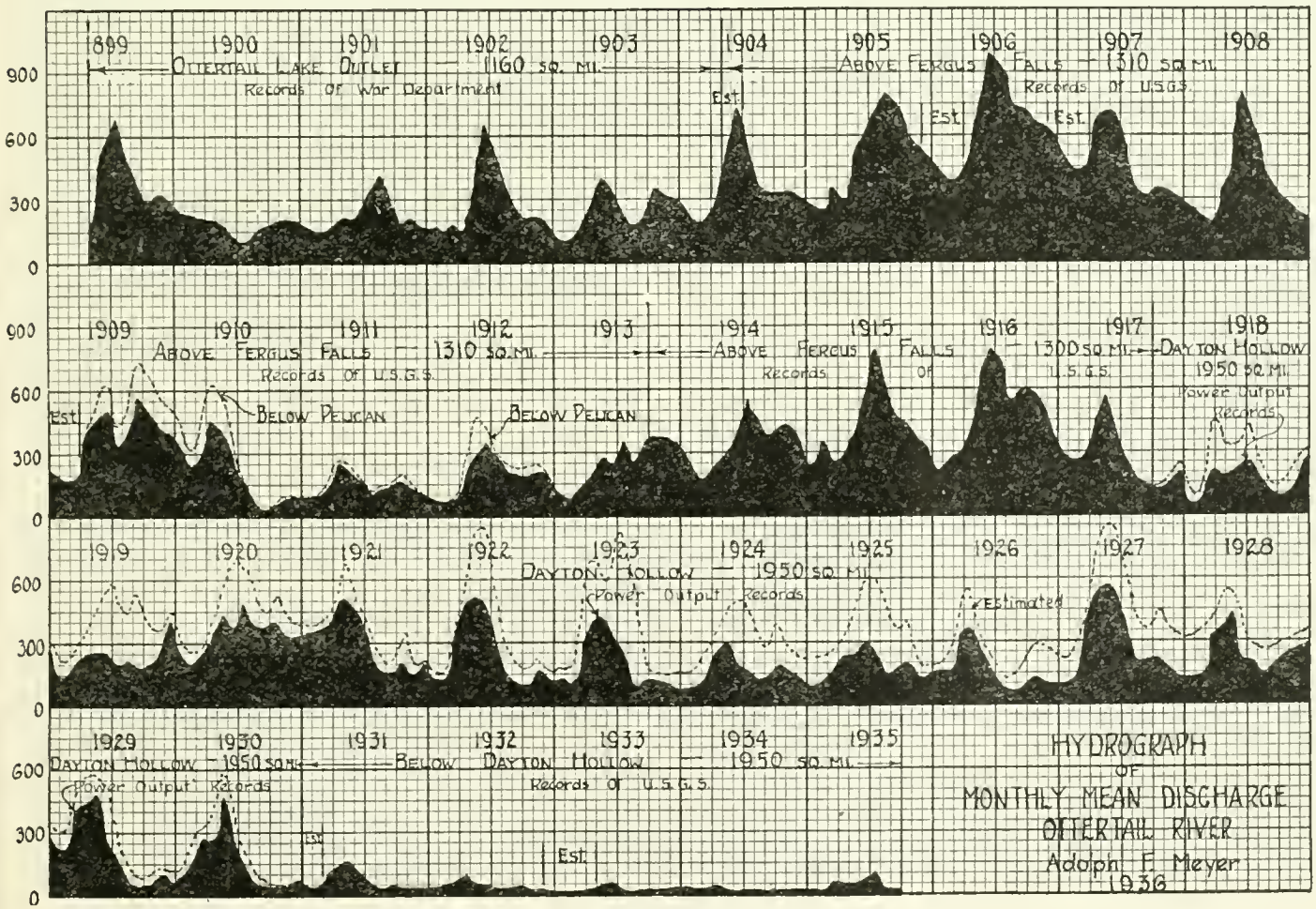


FIGURE 15

plateau, about 30 miles long, with a fall of less than 1 foot to the mile. Some channel improvement and maintenance here appear a necessary part of any stream regulation program. Otter Tail Lake and Prairie Lake are near the lower border of this plateau. These lakes lie at two corners of an equilatoral triangle at approximately the same elevation, with Fergus Falls at the third corner about 20 miles away and 200 feet lower.

In general, the lakes on the higher ground of the basin with relatively small drainage area show the greatest fluctuation in level over long periods. Those lakes which lie on the main streams, on the whole, show small fluctuation because of the regulating effect of all the lakes in the basin above, and better ground water support.

During normal years, the Otter Tail Basin shows a fair yield, notwithstanding the necessarily high evaporation and transpiration loss. Although the slopes are steep, the ground is fairly absorptive. Everything points to a normally good ground water supply. During long periods of deficient rainfall, however, the ground water topography flattens out, the lakes derive little support from ground-water inflow, rains are insufficient to produce surface run-off, and evaporation from the lake areas themselves greatly exceeds precipitation on those areas. The inevitable result is levels below zero flow on most of the lakes at the end of a succession of extremely dry years such as the period from 1930 to 1935.

Reservoir Types

There are two types of reservoirs which may be created in the Otter Tail Basin. The one type consists of primary storage reservoirs on lakes of relatively large area and small drainage basin. The other type consists of flow-regulating reservoirs on lakes which are merely enlargements of the main stream channels themselves. Lakes of the latter type are normally supplied with ample inflow, and from such lakes peak inflow and peak outflow are substantially equal in magnitude and coincident in time. Lakes of the former

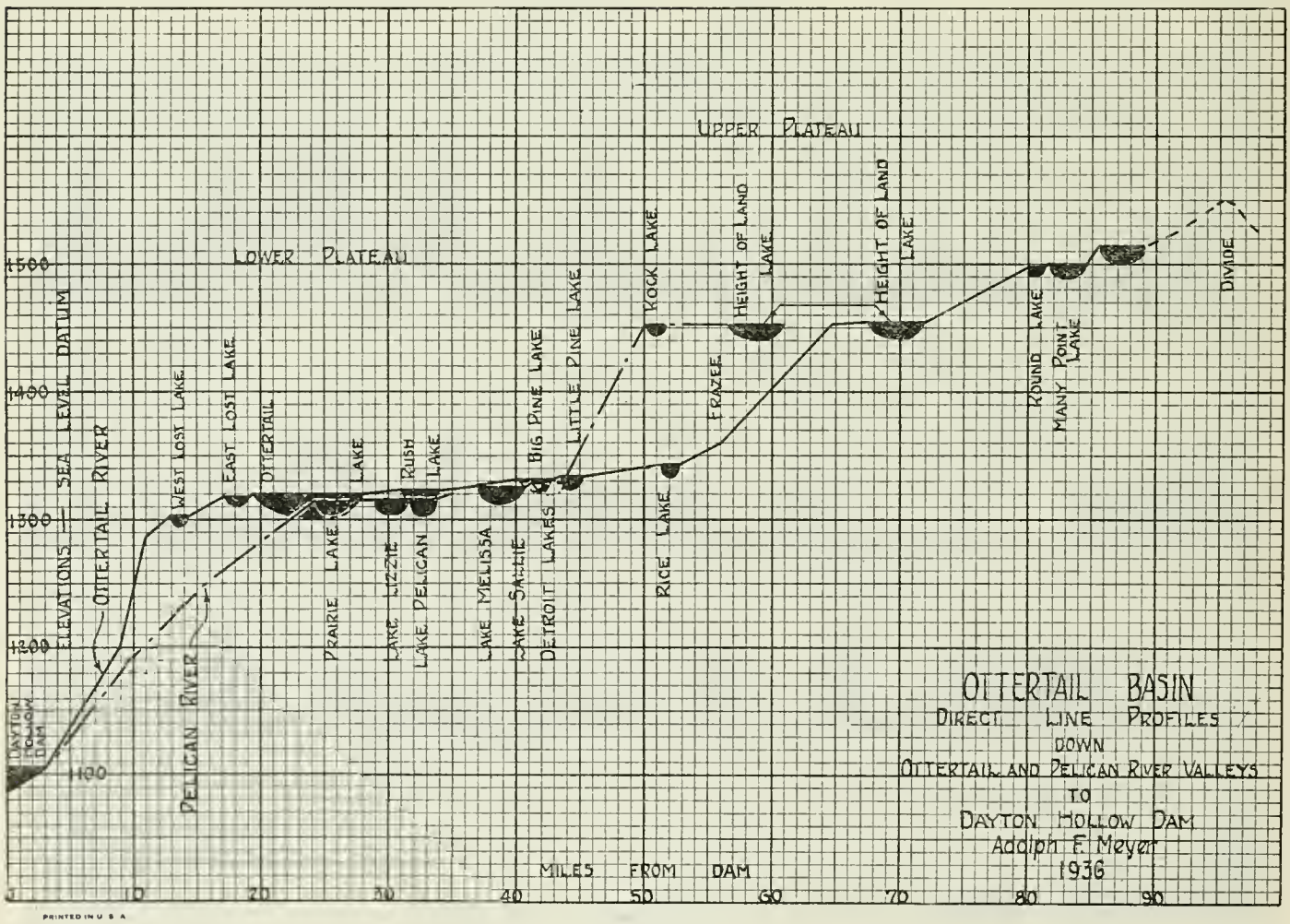


FIGURE 16

type have inflow rates far in excess of their peak outflow rates, and maximum inflow precedes maximum outflow considerably in time. Lakes of this type are the best for long-time storage of water and for increasing percolation to ground water. The second type of lakes is particularly useful for ordinary equalization of flow.

They can usually be filled annually. As a rule, only the largest of these lakes can hold substantial volumes of water in storage for augmenting the rare flows. It is primarily a question of the relation of lake area to tributary drainage area.

Lakes, such as Otter Tail and the group of lakes above Pelican Rapids, consisting of Prairie, Lizzie, Lida, and several smaller lakes, have the characteristics of both types of reservoirs. They have sufficient area to permit storage of water for long-time equalization of flow in addition to serving as normal-flow regulating reservoirs, and, therefore, are the most useful in the basin.

Otter Tail Lake Levels

Notwithstanding the relatively uniform level normally observed in Otter Tail Lake, the available records indicate that there has been substantial fluctuation in level during past years. Through the courtesy of the Otter Tail Power Co., records of the level of Otter Tail Lake at the outlet have been secured from November 1924 to date. Occasional levels were taken by the United States Geological Survey and the Civilian Conservation Corps during 1933, 1934, and 1935. A hydrograph of lake levels follows.

The records supplied by the power company show a high level of 1,319.33 in June 1927 and a low of 1,317.71 on October 22, 1931, after the dam was built in the outlet. This represents a variation of 1.6 feet. The records further show that the lake reached a maximum of 1,319.60 on June 21, 1935, under control. The lowest level reached since 1924 is 1,317.68 in December 1934 and 1,317.71 in October 1931—a range of only 1.9 feet in 12 years.

Apparently the low-water level of this lake was not permitted to drop to as low an elevation as the lake would have attained during the recent dry years if there had been no dam at the outlet. For example, on September 27, 1933, when the lake level was 1,318.67, the level below the dam was 1,317.80. On June 26, 1934, when the lake level was 1,319.11, the lake level below the dam was 1,317.54. On November 7, 1935, when the lake level was 1,318.49, the level below the dam was 1,318.01.

The available old records indicate that in 1897 Otter Tail Lake reached a stage of 1,322. In June and July 1899, it reached a stage of 1,321.45, but, at that time, the level was controlled. In July and August 1901 the controlled level reached 1,320.95. The low water of September 1910 was 1,317.5. It appears that the extreme range in level of Otter Tail Lake has been about 4.5 feet.

An analysis of the available data indicates that, during more than half of the 20 years from 1899 to 1919, Otter Tail Lake reached levels in excess of 1,320, and frequently reached a stage of 1,320.5. The normal high level was about 1,320 to 1,320.5.

The condition of the natural channel at the outlet of the lake indicates that the extreme low water level of Otter Tail Lake is below 1,317.0, and that, during the dry period ending in December 1934, riparian owners below the lake received somewhat less water than they would have under natural conditions. It would appear to be entirely in line with natural regulation to allow Otter Tail Lake to be drawn below a level of 1,317.0 during a period of extreme dry years in order to maintain a reasonable supply of water for domestic purposes in the Otter Tail River and the Red River of the North. At such times, recreational use of Otter Tail Lake should be subordinated to necessary domestic water supply. Certainly lower riparian owners can demand the natural low water outflow when needed.

The records show that, during the summer months, the outflow from the lake has been seriously affected by weed growth. During the winter, the outflow has been affected by ice conditions. No constant relation exists between lake stage and discharge. This prevents accurate estimates of outflow from observed lake levels.

Ground Water Storage

During an extreme dry period, the release of water from storage reservoirs will yield more than the volume represented by the drop in lake level. The ground water will contribute a substantial flow. Similarly, the retardation of outflow from other lakes in the basin, through dam regulation, will increase percolation to ground water and thus improve stream regulation to a greater extent than is represented by the surface storage available in those lakes at the beginning of a dry period. In this respect, the Otter Tail Basin differs radically from the rocky basins of northeastern Minnesota, where ground water storage is nil.

Further Flow Equalization

Although the Otter Tail Basin is naturally well regulated, it is entirely practicable further to equalize the flow of the stream below Fergus Falls by the creation of a large number of small storage and regulating reservoirs in the basin.

In computing the effect of storage reservoirs, however, care must be taken not to overestimate the regulating effect of the available volume of surface storage. It is not correct, for example, to assume that the entire volume of water between low water and full reservoir

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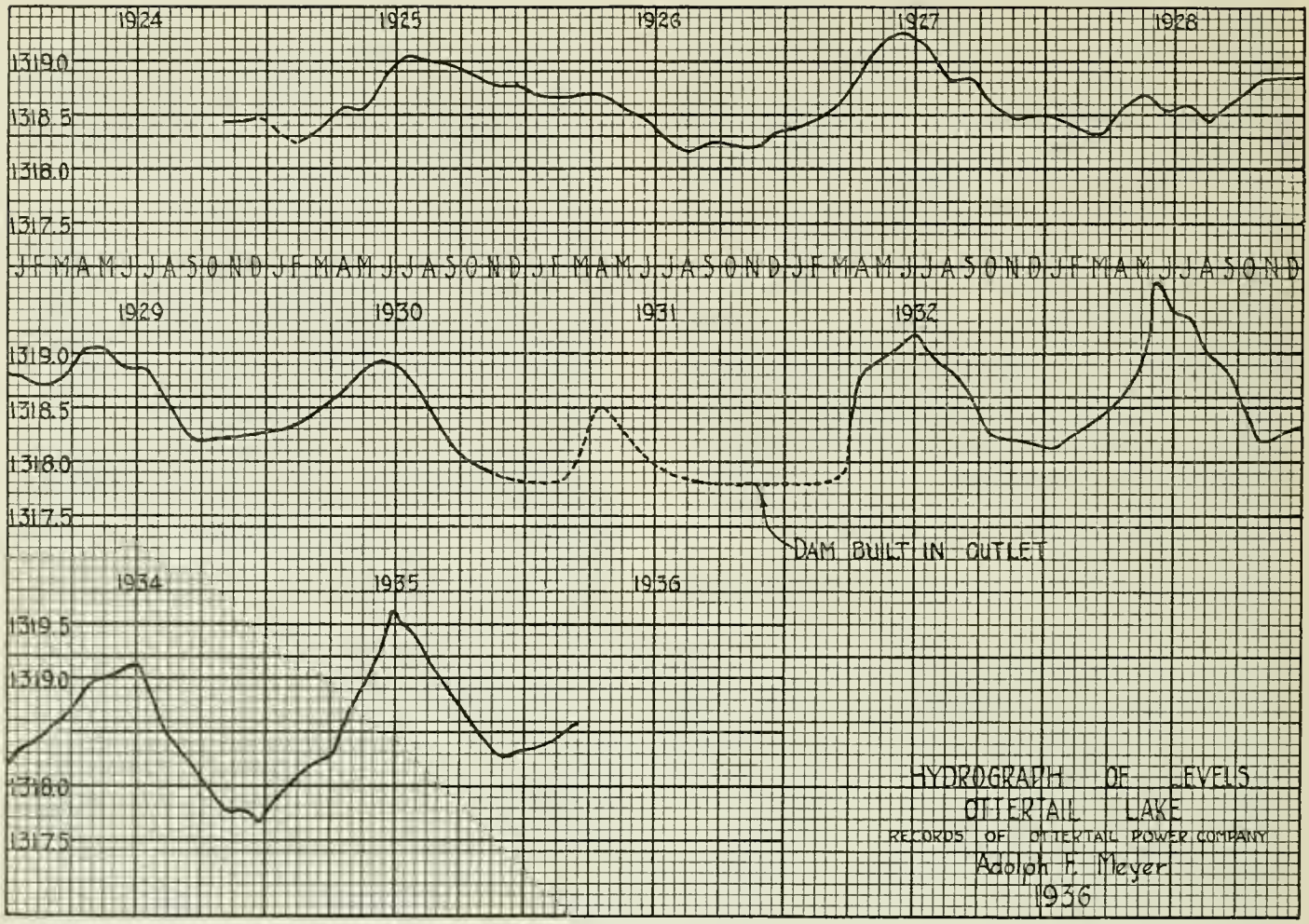
1924
1925
1926
1927
1928
1319.0
1318.5
1318.0
1317.5
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1929
1930
1931
1932
DAM BUILT IN OUTLET
1934
1935
1936
1319.5
HYDROGRAPH OF LEVELS
OTTERTAIL LAKE
RECORDS OF OTTERTAIL POWER COMPANY
Adolph F. Meyer
1936

Figure 17

level represents storage which is available for equalizing stream flow. As a matter of fact, unless either the low-water level of a lake is lowered or the high-water level is raised, the artificial surface storage effect is relatively small. This is true because man is doing nothing more than to utilize the same storage capacity that nature utilized. The best that man can do under those circumstances is to retard the outflow and thereby to lengthen the period during which the stored water is released. This means primarily annual equalization of flow, as against long-time equalization.

No great increase in the extreme low-water flow of any stream over a period of years can be produced through surface run-off by merely utilizing the natural storage range of the lakes in the basin. The long-time equalization of surface flow effected by a given reservoir is measured by the volume of water in the reservoir at the beginning of the drought period in excess of the volume which nature would have stored there. On the other hand, retardation of outflow will increase percolation to ground water and thereby tend to maintain a higher ground water level throughout the basin. Thus, ground water storage will become available during an extreme dry period of years when all of the lakes drop below the normal low-water levels, and often far below the level of zero outflow. When run-off is reduced to an inch or less a year from the drainage basin, a little flattening of the ground water topography can produce a substantial flow.

A list of 57 lakes in the Otter Tail Basin, constituting possible W. P. A. projects, has been furnished me, giving the area in acres and the possible depth of control between the level of the outlet channel, i. e., the level of zero flow, and the high-water level. This "control depth" is 6.0 feet on Otter Tail Lake, 7.5 feet on Rush, 7.5 on Detroit Lakes, 12.0 on Melissa, and from 4 to 6 feet on most of the other lakes. The total lake area tabulated is 99.067 acres, representing a possible so-called storage capacity of 518,700 acre-feet. This amount of water would have supplied 142 cubic feet per second for 5 years. Obviously, however, only a small portion of this storage space can ever be available for further regulation. Nature already utilizes most of it.

Summer resort lakes cannot be fluctuated greatly without insurmountable opposition. Moreover, no such volume of stored water is needed for domestic and sanitary purposes down river and cannot economically be provided for any or all conceivable purposes on the Red River of the North.

So far as surface storage is concerned, the crux of this entire problem lies in the determination of the natural lake levels which existed in this basin at the beginning of the recent unprecedented drought, and the extent to which these levels could have been increased economically by storage.

In April 1932, a discharge of 10,200 cubic feet per second was recorded in the Red River at Grand Forks. This is 25 percent of the maximum observed flood flow. At Fargo, where the drainage area is 6,420 square miles, 868 cubic feet per second was observed on April 11. The Otter Tail, below the mouth of the Pelican, discharged 242 cubic feet per second on April 10, but averaged only 82 cubic feet per second for the month. Basins adjoining the Otter Tail in the west, north, and east showed considerable spring run-off. The Mustinka, with 1,460 square miles, discharged 173 cubic feet per second on April 7. The Buffalo, near Dilworth, discharged 311 cubic feet per second on April 12. The Wild Rice at Twin Valley, with 805 square miles, discharged 295 cubic feet per second on April 9. The Crow Wing at Nimrod averaged over 400 cubic feet per second during April and May, from a drainage area of 1,010 square miles.

Notwithstanding good spring run-off from surrounding basins and a level of 1,319.15 in Otter Tail Lake on June 30, 1932, representing a rise from 1,317.73 the previous November, extreme low-water conditions were encountered at Fargo by the end of November 1932 when zero flow was recorded. The mean discharge of the Otter Tail below the Dayton Hollow Dam in November 1932 was 18 cubic feet per second. Evidently this small flow was lost by the wayside.

A relatively narrow, deep, and straight improved channel is necessary for carrying small flows between Otter Tail Lake and Breckenridge. The effectiveness of channel improvement was demonstrated in the fall of 1934 when water released from Otter Tail Lake was carried down to Fergus Falls and Breckenridge in greatly reduced time through a channel improved in August and September of that year.

The available records of spring run-off on the Otter Tail and adjacent basins indicate that in April and May of 1932 most of the lakes in the basin must have been at a fairly high stage. The effect of possible future surface storage must be measured from the conditions which existed in the basin in the spring of 1932. There is no indication that sufficient storage capacity can be provided in the basin for carrying forward water stored from the freshets of 1930 or 1931, except probably on the outlying lakes in the basin which have small drainage areas.

Contribution of Lakes to Run-off

The following table presents data and computations bearing on the question of the extent to which lake areas contribute to stream flow. A glance at the columns of gain and loss indicates that the contribution of lakes varies from large plus values to large minus values, depending upon the rainfall and the monthly temperature, relative humidity, and wind velocity.

The maximum excess precipitation over evaporation was substantially 16 inches in 1916. The maximum excess of evaporation over precipitation was more than 20 inches in 1934. These records emphasize the need for more stations in Minnesota and elsewhere, at which relative humidity and wind velocity are measured. Another station is needed in southwestern portion of the State. Mr. Hovde, the local United States meteorologist, has recommended the establishment of a complete Weather Bureau station at International Falls.

When the variation from a gain, or excess precipitation, of more than 1 foot to a loss, or excess evaporation from lake areas of from 1 to 2 feet is noted, it becomes apparent that the assumption that precipitation and evaporation balance each other is far from the truth, except as a general average over a long period of years.

Since storage projects are concerned with the conservation of water for use during dry years, the necessity for taking into consideration a continuous excess of precipitation from water areas for a number of years in succession becomes apparent.

Evaporation was computed by means of the Meyer formula, using the monthly mean temperature at Fergus Falls and the monthly relative humidity and wind velocity at Moorhead, with a coefficient of 11 in the formula. From 1888 to 1890, Moorhead temperatures were used because no observations were available for Fergus Falls.

From 1901 to 1909, inclusive, water areas contributed a total of over 6 feet in depth due to excess precipitation over evaporation loss.

From 1928 to 1935, inclusive, water areas lost over 6 feet in depth due to excess evaporation over precipitation.

Mass Curve of Inflow

From the actual observed outflow and lake level, with some values estimated where no actual records were available, the following mass curve of inflow into Otter Tail was prepared.

For the purposes of studying the regulating effect of this lake, an ordinary maximum level of 1,320.5 was

Otter Tail Basin—contribution of lakes to run-off

[Inches depth on water area]

Year	Precipitation	Evaporation	Gain	Loss	Year	Precipitation	Evaporation	Gain	Loss	Year	Precipitation	Evaporation	Gain	Loss
1888	19.66	21.57		1.91	1905	30.40	15.68	14.72		1922	25.40	27.11		1.71
1889	15.87	27.02		11.15	1906	31.00	15.72	15.28		1923	22.90	25.75		2.85
1890	20.16	24.24		4.08	1907	21.00	17.30	3.70		1924	24.00	23.84	.16	
1891	20.15	26.39		6.24	1908	28.30	19.30	9.00		1925	25.70	23.25	2.45	
1892	26.61	17.62	8.99		1909	29.00	15.83	13.17		1926	22.40	26.62		4.22
1893	22.14	23.61		1.47	1910	13.80	25.23		11.43	1927	24.50	21.81	2.69	
1894	15.77	31.02		16.25	1911	24.40	19.90	4.50		1928	25.00	27.19		2.19
1895	21.83	27.09		6.26	1912	25.90	20.27	6.63		1929	19.40	27.03		7.63
1896	34.00	23.82	10.18		1913	28.50	21.02	7.48		1930	19.40	29.22		9.82
1897	22.80	20.95	1.85		1914	26.70	19.73	6.97		1931	22.10	29.77		7.67
1898	21.20	22.59		1.39	1915	27.90	16.22	11.68		1932	19.60	28.80		9.20
1899	26.90	22.87	4.03		1916	32.20	16.22	15.98		1933	22.10	34.78		12.68
1900	26.20	27.24		1.04	1917	16.70	21.20		4.50	1934	14.70	34.89		20.19
1901	25.10	21.08	4.02		1918	20.90	23.18		2.28	1935	22.30	27.12		4.82
1902	23.40	19.21	4.19		1919	30.20	20.23	9.97						
1903	26.10	21.13	4.97		1920	24.20	20.08	4.12		Mean	23.67	23.29	.38	
1904	23.40	19.15	4.25		1921	24.60	27.09		2.49					

assumed. This substantially represents ordinary high water according to the available information. During extreme flood inflows, water should be stored up to about 1,322.0 if necessary. This represents the high water of 1897. Below a level of 1,320.5, water should be released sparingly, depending upon storage available on lakes above Otter Tail. When a stage of 1,319 is reached, the release should be limited to the most urgent needs for domestic and sanitary purposes. At the end of a period of extreme drought such as 1934, the lake might be drawn down to 1,316.5. This is approximately its natural extreme low level under such conditions as those which prevailed recently.

As previously stated, the effect of surface storage in lakes is determined by the extent to which the natural lake levels at the beginning of the drought period could have been increased by regulation and the extent to which the levels prevailing at the end of the period could have been reduced through regulation. The mass curve shows that, insofar as the low-water reserve in Otter Tail Lake itself is concerned, the drought began July 1, 1932. At Fargo, the river dropped to a mean of 33 cubic feet per second in June 1932. At that time, Otter Tail Lake was at an elevation of 1,319.05. This is 1.45 feet below the proposed regulated level. On March 1, 1935, when there again was sufficient flow at Fargo, Otter Tail Lake was at 1,318.15. It is proposed to permit drawing the lake to 1,316.5 under similar conditions.

The natural range in levels of Otter Tail Lake between the beginning and the end of the governing drought period at Fargo was only 0.9 foot. It is proposed to increase this range to 4.0 feet. The additional 3.1 feet of storage on Otter Tail Lake would have permitted the continuous discharge of an additional 23 cubic feet per second.

During some spring months, however, no additional water is required at Fargo. During March, April, May, and June 1933, and April 1934, the stream flow at Fargo was ample. From June 1932, to March 1935, the flow at Fargo was less than 50 cubic feet per second for 28 months.

The average flow at Fargo from July 1932 to December 1935 was exactly equal to the average flow of the Otter Tail below the Dayton Hollow Dam.

The loss in transit between Otter Tail Lake and Fargo appears to vary between 10 and 20 cubic feet per second. An improved channel, by reducing the water surface and the time of transit, should reduce this loss more than the increased stage (corresponding to the increased regulated flow) would increase the loss.

From June 1, 1932, to March 8, 1935, the aggregate deficiency in stream flow below 50 cubic feet per second at Fargo was 1,188 cubic feet per second months, or 22,500 acre-feet. No deduction is made for excess spring run-off at Fargo, which, of course, could not have been stored. Only a negligible portion of it came from Otter Tail Lake.

An additional storage of 3.1 feet on Otter Tail Lake between the levels previously stated represents 45,700 acre-feet, or 755 cubic feet per second months. This storage would have maintained a flow of 35 cubic feet per second at Fargo. The remaining deficiency of 15 cubic feet per second could have been supplied from 26,000 acre-feet of additional effective storage on other lakes above Otter Tail and on the Pelican River.

Storage on Pelican River

According to the available information, there has been practically no flow at the mouth of the Pelican River, except a little run-off from local showers, from 1930 to 1935. Most of the lakes in the basin fell sev-

eral feet below the level of zero outflow. Just what the stage in these lakes was at the beginning of the drought, no one knows. It is probable, however, that 2.5 feet of effective storage could have been made available on Prairie, Lida, Lizzie, and Crystal Lakes. The combined area of these lakes, below the meander line, is 12,500 acres. Assuming an average area of 11,000 acres, there would have been 27,500 acre-feet of storage available. This amount added to 45,700 acre-feet on Otter Tail Lake would have provided a total of 73,200 acre-feet of effective storage, which is sufficient to assure a minimum flow of 50 cubic feet per second at Fargo under conditions that resulted in an unregulated minimum flow of less than 10 cubic feet per second for 20 months between June 1932 and March 1935.

A dam above Pelican Rapids will control the level of Prairie, Lida, and Lizzie Lakes. Better channel interconnection should be provided between these lakes. Lida can be raised with Pelican River water before run-off from its own small basin would return it to normal. This will help Lida, while, at the same time, storing spring run-off and increasing percolation.

Additional storage may advantageously be provided on such lakes as Height of Land and Round Lakes on the main stream and outlying lakes such as Star, Dead, Long, and Cormorant, with small drainage areas.

Methods of Regulation

The results here set forth represent what could have been accomplished if the reservoirs had been in existence. In order to insure that such benefits will be realized in the future, the reservoirs must be controlled by competent authority; the available stored water must be conserved and judiciously utilized through the years of drought in spite of adverse protests from conflicting interests.

Although more stored water could be released during ordinary low-water years, there is always the danger that the following spring may not yield sufficient inflow to fill the reservoirs again, and then it will be impossible to maintain the contemplated dependable flow. The very essence of the expression "dependable flow" is a flow that will not fail under the most serious conditions reasonably to be anticipated. This means that during ordinary droughts like that of 1931, the available stored water must not be drawn upon to an extent sufficient to increase the flow at Fargo to more than 50 cubic feet per second; otherwise the reservoirs cannot be refilled in the succeeding spring like that of 1932, and, therefore, the so-called "dependable outflow" cannot be maintained during the following years of extreme drought like 1933 and 1934. There will be many times when those in control of the reservoir will be urged to release more water,

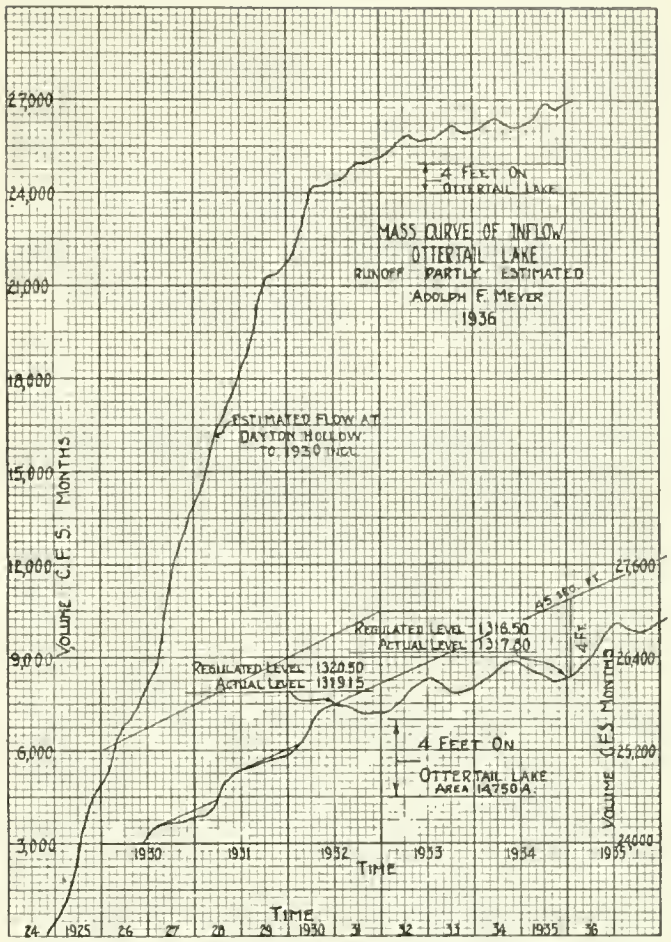

FIGURE 18

and perhaps 9 years out of 10, or even more than that, additional water could be released during dry summers and the reservoirs refilled during the following spring. Those instances will be cited, and the governing authority chided for its timidity, but the day will inevitably come when the so-called "dependable flow" cannot be maintained if higher rates of flow are permitted during ordinary years so as to deplete the storage to an extent where the reservoirs cannot be refilled during the following spring.

While aiming to conserve water for maintaining the given dependable flow at Fargo, the necessity for flood control in wet years must not be overlooked. Whenever sufficient run-off to fill the reservoirs is assured, water must be wasted. During periods of excessive flood inflow into the large reservoirs on the main stream, water must be wasted promptly, and wasting at relatively high rates must continue until the lake level is down again to the established ordinary maximum.

Each main-stream reservoir will consist essentially of two parts—a low-water reservoir and a flood reservoir. Both parts will, to some extent, be used also

for annual flow equalization. However, the practical depth of storage on the lakes in this basin is so small that no definite amount of storage can be set aside for annual flow equalization in the interest of power development. Such benefits must remain incidental to the use of the available storage capacity for water conservation on the one hand, and flood prevention on the other. There will be material equalization in the flow of the main stream, but the release of stored water must be governed by domestic and sanitary water needs and with a view to reducing flood crests.

Storage on Other Lakes

There are many other lakes in the Otter Tail Basin which may desirably be controlled. Such lakes as Height of Land and Round, on the main stream, are satisfactory reservoirs for improving surface flow. Other lakes with small drainage areas such as Star, Dead, Long, and Cormorant can only be used to increase percolation and evaporation and help with annual flow equalization during normal years. From the viewpoint of increasing low-water flow during extreme drought periods, such lakes serve only through their effect in maintaining better ground water levels in the vicinity. In some cases, this effect will be too local to be of any value to the main stream. However, stabilization of levels on outlying lakes with small drainage areas, by holding back spring run-off until fall or until it disappears through evaporation and percolation will improve the recreational value of these lakes by providing more uniform summer levels.

Although the beneficial effects of storing water on outlying lakes with small drainage basins may not be readily demonstrable insofar as the main stream is concerned, nevertheless there is certain to be some regulatory effect during ordinary years. So far as extreme floods on the main stream are concerned, the effect is not likely to be beneficial because ordinary run-off will normally have filled all of these lakes to the point of overflow before extreme flood-producing conditions prevail over the whole basin.

Control Works

In providing control works on all lakes with large tributary drainage areas where it is not intended to raise the natural extreme high-water level, it is necessary to provide an outflow capacity at the higher lake stages in excess of that prevailing under natural conditions, and constant regulation is required. The dam itself should be made a little wider than the narrowest point of the natural outlet. The sill should be placed a little below the natural stream bed, and the channel immediately below the dam should be cleaned out so as to provide a better get-away in time of high water. If this is done, the spring run-off can be stored and, instead of allowing it to run out during the early summer, it can be held until late fall and winter.

If, under those conditions, with a lake level higher than natural, excessive summer or fall rains are experienced, the control dam must be opened so as to provide more rapid outflow than nature would have provided at that stage. Otherwise the lake will inevitably rise to a stage in excess of its natural high-water level.

In the case of outlying lakes with small tributary drainage areas, it appears desirable, in order to reduce maintenance and operation costs and to make outflow capacity instantly available in case of excessive rainfalls of short duration, to use long overfall dams with a small sluice, together with channel improvement below the dams. Pipes should be placed in the crests of the dams to permit the use of flashboards which would go out during extreme local floods.

There is a decided advantage in building pier and stop-log dams in the outlets of outlying lakes, depending upon manual control so as to be able to build these structures before the property owners around the lake have come to an agreement on desirable lake levels, or flowage rights have been acquired; but such structures possess one undesirable feature—namely, there is complete dependence on manual control of outflow even though flood crests on these lakes may be reached a few hours after the beginning of excessive rainstorms. The man who is supposed to take out the stop logs may live near the dam, but excessive rains may occur on holidays, wedding days, and other special occasions when he may be absent, or perhaps he may be too fully occupied with saving hay, grain, stock, or other property to go to the dam through a pouring rain.

Even though it represents partial duplication of structures, there is much to be said in favor of the construction of long overfall weirs with reasonably adequate stop-log sections in the center so that excessive flood inflows of short duration may find escape over the long overfall weirs even if the stop logs are not removed. Until the property owners are ready to have the lake fully controlled, all, or part, of the stop logs may be kept out of the dam.

Required Tributary Land Areas

Outlying lakes with small drainage areas cannot be depended upon for surface storage during periods of extreme drought because the tributary drainage areas are not sufficient to maintain the lakes at their normal levels, much less afford increased outflow. During such periods of extreme drought as the recent one, evaporation from water areas so far exceeds precipitation on those areas that lakes in the Otter Tail Basin may be expected to shrink to an area such that the tributary land area is about 10 times the exposed water area. In other subbasins of the Red River of the North,

where the run-off from the land area is less, the ratio of required land area to water area is much greater.

By way of illustration, it may be noted that in a year like 1934, the evaporation from water area was about 20 inches in excess of the precipitation on those areas. During that year, the yield of the land areas was generally less than half an inch. If such conditions continued for several years, the lake area would shrink until it was one-fortieth of the size of the tributary land area. On basins from which the average run-off is one-tenth of an inch, the required ratio of land area to water area, in a year like 1934, is 200 to 1. The reason for the lowering and shrinkage of lakes during the recent drought is apparent.

Storage in Lake Traverse

The extent to which it is physically possible to utilize Lake Traverse as a reservoir for conserving water during wet years for domestic and sanitary use on the Red River of the North may be determined by balancing rainfall on the lake and inflow into the lake from the tributary drainage area against outflow from the lake and evaporation from the lake surface during such a dry period as that which extended from 1930 to 1935.

Physical Data

The area of Lake Traverse has varied through the years from over 30 square miles at high stages such as that of 1916 to nothing in November 1934. During July, August, and September of that year, evaporation exceeded precipitation on the lake by more than 11 inches and the tributary streams were all dry.

The area of the tributary basin at White Rock is 1,335 square miles. The supply to the lake is derived largely from surface run-off following heavy spring and early summer rains, particularly when these are preceded by heavy winter snowfall. Some low-water inflow comes from the Moraine area of the upper Mustinka Basin which adjoins the Otter Tail Basin. At the end of a period of extreme drought the groundwater supply to this lake completely vanishes.

The area of the Mustinka Basin at Wheaton is 775 square miles. Records of the flow of the Mustinka and of the outflow from Lake Traverse were furnished by the United States Geological Survey. No records of the level of Lake Traverse during the last 5 years were available, outside of the fact that the lake was entirely dry in 1934 and that in 1935 it had recovered sufficiently to be about three-fourths of a mile wide with a maximum depth of about 2 feet. Residents around the lake may have made some observations which would be useful if available.

Outflow from Lake Traverse ceased completely in July 1930. The stage of zero outflow is about 971.5. In June 1922, which is the last available record of lake level, the elevation was 973.3. During 1924 and 1925, there was no outflow whatsoever, and there was practically none during 1926. The entire outflow from 1923 to 1930, inclusive, was 29,000 acre-feet, corresponding to about 2 feet depth on the lake.

Computed Evaporation Loss

In the absence of lake level records since 1922, the evaporation loss from Lake Traverse has been computed by the Meyer formula, using the monthly mean temperature at Beardsley and the monthly mean relative humidity and wind velocity at Moorhead, about 90 miles north of the lake.

The following table summarizes by years the annual precipitation and computed evaporation, together with the annual gain or loss from 1894 to 1935.

During 1894, 1910, 1921, 1922, 1929, 1930, 1931, and 1932, evaporation exceeded precipitation on the lake by about 1 foot. During 1933 and 1934 the excess was over 22 inches. The total excess from 1931 to 1934 was 72 inches. The average excess from 1894 to 1935 was 1.7 inches a year.

During 1935 the rainfall on the lake almost equaled the evaporation. There was about 7,000 acre-feet inflow from the tributary drainage area. As a consequence, the lake, which had been completely dry in 1934, made sufficient recovery to be about 2 feet deep at the deepest point.

During 1930 the outflow from the lake was 6,600 acre-feet. During 1931 there was no outflow. The inflow from the tributary drainage area was only about 1,300 acre-feet. During 1932 and 1933 the inflow was about 2,000 acre-feet each year. During 1934 the inflow was about 600 acre-feet. The total inflow from October 1, 1930, to the end of 1934 was 5,900 acre-feet. During this time the lake area shrank in size from about 20 square miles to nothing.

Checks on Computed Evaporation

If Lake Traverse is regulated, it will be necessary to assume an average lake area of more than 25 square miles. The total inflow from 1931 to 1934, inclusive, represents only about half a foot in depth on this lake area. During the same period, the total evaporation loss from the water area exceeded the precipitation on that area by 72 inches. In other words, if we assume that Lake Traverse had been converted into a reservoir which was full to a level of 975 on October 1, 1930, then the level of the lake would have fallen to 969.5 by the end of 1934, even if no water whatsoever had been released for use on the river below. Evidently, the lake would have to be raised to a much higher level to afford any useful storage capacity during a period of extreme drought.

Evaporation was computed by means of the Meyer formula, using the monthly mean temperature at Beardsley and the monthly mean relative humidity and wind velocity at Moorhead, with a coefficient of 11 in the formula.

Monthly mean precipitation at Wheaton and Beardsley was averaged from 1915 to 1935. Prior to 1915, Beardsley records alone were available.

During the 15 years from 1921 to 1935, the computed evaporation loss continually exceeded the precipitation on the lake area. The total excess evaporation was 12.5 feet.

During the 6 years from 1911 to 1916, precipitation continually exceeded the evaporation from the lake area. The total excess precipitation was nearly 4 feet.

During the 8 years from 1902 to 1909, the excess precipitation was nearly 5 feet.

From 1931 to 1934, computed excess evaporation over precipitation and inflow should have lowered Lake Traverse about 5.5 feet, from a level of about 971 to about 965.5. Actually, the lake was dry in November 1934. No exact information is available respecting the elevation of the lake bottom. The lowest recorded soundings show levels in excess of 967, but these do not cover the main body of the lake which is probably at an elevation of about 965. This constitutes a fair large-scale check on the evaporation computations.

The last heavy inflow into Lake Traverse occurred in the spring of 1922. From October 1, 1921, to September 30, 1922, the Mustinka delivered 42,000 acre-feet, equivalent to nearly 3 feet depth on the lake. The remainder of the tributary drainage basin probably delivered about 10,000 acre-feet more. The outflow from Lake Traverse that year was 35,000 acre-feet, leaving a balance of 17,000 acre-feet. The computed excess evaporation of 14.3 inches for that water year represents about 16,000 acre-feet. The lake level was only slightly lower at the end of the year than it was at the beginning. This also constitutes a reasonably good check on the evaporation computations.

Lake Levels and Outflow

During the high-water years of 1914, 1915, and 1916, Lake Traverse could have been filled to practically any level which may conceivably be established for regulation purposes. The reservoir could have been kept nearly full during the following years.

During 1921 there was a small, fairly uniform outflow from the lake during most of the year, indicating a lake stage of slightly over 972. In August, the flow dropped to practically nothing, but there was a little recovery in September as the result of heavy rains. Beardsley, near the lake, recorded 6.15 inches.

In the spring of 1922, based upon the discharge records and a lake level reading of 973.3 on June 1, 1922, the lake reached a stage of 974.4. Judging from the discharge records, Lake Traverse remained close to 972 throughout the year 1923. During 1924 and 1925 it fell below that level. During 1926 there was a very slight outflow in March and none the rest of the year, indicating a level below 972. The year 1927 was a year of heavy fall and winter precipitation with spring floods in most of Minnesota. However, the rainfall records do not indicate unusual conditions around Lake Traverse, except for heavy April, May, and June precipitation. This is reflected in an outflow of 40 cubic feet per second in April with a lake stage of about 972.5. The average outflow for the year was 10 cubic feet per second.

From 1923 to 1930, the total outflow from the lake was 29,000 acre feet, or about 3,700 acre feet a year. This would probably have been just about sufficient to maintain the larger lake area at a higher regulated level. From 1931 to the end of 1934, there would have been a net loss due to excess evaporation of 5.5 feet in

Lake Traverse Basin—Contribution of lakes to run-off

[Inches depth on water area]

Year	Precipitation	Evaporation	Gain	Loss	Year	Precipitation	Evaporation	Gain	Loss	Year	Precipitation	Evaporation	Gain	Loss
1894	17.86	32.65		14.79	1909	19.30	16.18	3.12		1924	23.56	24.20		0.64
1895	18.16	27.98		9.82	1910	15.46	25.53		10.07	1925	17.68	24.40		6.72
1896	31.60	24.15	7.45		1911	28.23	20.19	8.04		1926	18.86	26.90		8.04
1897	27.70	21.61	6.09		1912	25.73	21.01	4.72		1927	20.19	22.00		1.81
1898	24.02	22.63	1.39		1913	25.67	22.26	3.41		1928	21.26	28.00		6.74
1899	31.28	23.42	7.86		1914	31.58	20.58	11.00		1929	17.75	28.20		10.45
1900	20.43	27.73		7.30	1915	26.16	17.12	9.04		1930	20.43	29.60		9.17
1901	20.16	21.89		1.73	1916	27.10	17.50	9.60		1931	17.64	32.00		14.36
1902	24.56	19.41	5.15		1917	16.24	21.86		5.62	1932	16.62	29.20		12.58
1903	26.97	20.97	6.00		1918	23.00	23.93		.93	1933	15.64	38.20		22.56
1904	24.87	19.28	5.59		1919	24.24	24.66		.41	1934	13.72	36.20		22.48
1905	25.11	15.62	9.49		1920	25.46	21.71	3.75		1935	24.70	26.90		2.20
1906	30.74	16.16	15.59		1921	18.48	30.50		12.02					
1907	16.28	17.10		.82	1922	17.16	28.30		11.14	Mean	22.41	24.09		1.68
1908	31.63	18.98	12.65		1923	17.84	26.20		8.36					

depth. This would have brought the lake down to 974.5 if a regulated level of 980 had been established. If the lake had been drawn down to 971.5 by the end of 1934, it would have been possible to discharge about 30 cubic feet per second for 6 months of each year during the period of 4 years. No flood control would, of course, have been possible under such a plan of regulation. Storage above 980 would have been necessary during wet summers if the flood outflow from the lake was not to be greatly increased. About 4 feet would be necessary for ordinary flood control purposes above the stage of 980. Maximum flood inflows would require much more storage if outflow were limited to 1,000 cubic feet per second. However, it does not pay to build relatively expensive reservoirs for protecting agricultural lands from possible crop losses once in 50 or 100 years. This phase of the subject is discussed later.

Conclusions

It is evident from the data and considerations presented that Lake Traverse is of relatively little value for water conservation purposes. The tributary drainage area is small; the precipitation on the basin is low; and the evaporation loss from the lake itself is very high. Dean Chandler has estimated the average 53-year run-off from this basin as 0.2 inch per year, equal to 20,000 acre-feet per year. This is by far the lowest run-off from any portion of the basin of the Red River of the North. Dean Chandler's estimate checks my own, based on the period 1916 to 1935.

From the viewpoint of possible future control of Lake Traverse, two alternatives may be considered:

1. *Level Stabilization Project.*—A project of this type would aim at maintaining as uniform levels as possible without reference to the effect of such regulation on the outflow, which would inevitably be detrimental. A dam could be constructed in the outlet for the purpose normally of maintaining a level of 975 in the lake. Outflow capacity could be provided capable of discharging a sufficient portion of the maximum probable flood inflow to prevent the lake from exceeding its natural extreme high-water mark of about 977.2 established in 1882. An improved channel below the outlet of the lake would be required, capable of carrying away a discharge of 2,000 cubic feet per second at a lake stage of 975. This rate of outflow corresponds approximately to the natural flood outflow at the extreme high-water stage.

2. *Flow Equalization Project.*—A project of this type would result in large variations in lake level, but flood outflows would be reduced and low outflows would be increased. A dam could be constructed in the outlet of the lake with a crest elevation of about 988. Flowage rights would have to be acquired to elevation 985. In time of extreme flood inflow it might be necessary to permit the lake to rise to practically that level for a few days. A normal level of 978 could be established below which water would be conserved. The lake might have to be drawn down to a level of about 972 during extreme drought conditions. Such a project as this would prevent all ordinary flood outflows and materially reduce the maximum probable flood outflow. The Bois des Sioux River below the outlet of Lake Traverse should be improved to provide a channel capacity of about 750 cubic feet per second.

From the viewpoint of water conservation, such a project would provide about 2 feet, or 30,000 acre-feet, of effective storage to be held as a low-water reserve for emergency use in increasing the flow at Fargo during extreme droughts.

Under this plan of regulation there would be a maximum probable fluctuation in lake level from about 970 to 985, or 15 feet.

Flood Protection for Agricultural Lands

In considering flood protection for agricultural lands, two widely different situations present themselves:

1. The project may be for the protection of those low-lying lands which are parts of farms, the greater portion of which are not subject to overflow, with farm houses, barns, and other buildings above high water. Farm lands in the river valleys of the Northwest are generally of this type.

2. The project may be for the protection of farm lands in wide, flat valleys, subject to deep inundation, where the entire farms, together with the land on which the buildings are located, the roads, and all other improvements, are submerged below the flood-water plane to such an extent and for such a period of time as completely to demoralize life. Farm lands in the alluvial valley of the lower Mississippi, where the flood waters reach a width of 20 to 50 miles for weeks at a time, are of this type.

Although the lower portion of the Red River Valley is wide, by far the greater portion of the valley land belongs to the former class. Most of the farm buildings and parts of most farms are on ground which is above the flood level. The major loss is the crop loss.

It is necessary to determine the extent to which it is practicable and economical to protect agricultural lands from crop losses. Lands subject to spring floods may be cultivated later in the season. Usually they do not suffer seriously from the deposition of debris and sometimes profit materially from the deposition of comparatively rich silt washed down from the uplands.

Lands subject to summer floods may be cultivated if the floods do not occur too frequently; otherwise, they may be used as hay lands. The extent to which hay

lands are valuable depends upon the ability of the individual farmer to utilize the hay crops for feeding stock or for sale.

In 1922, in connection with Minnesota River projects, I made a rather complete analysis of the subject of protecting croplands and derived certain curves for use in determining the depreciation of lands subject to crop losses once in a given number of years. At that time I used relatively high values for lands and buildings and an interest rate of 6 percent. In the present instance I am using a land value of $60 per acre, exclusive of buildings, with interest and taxes at 5.5 percent.

The following analysis leads to the conclusion that it does not pay to protect agricultural land from crop losses which do not occur at least once in about 15 or 20 years, unless flood protection can be secured at relatively low cost. Usually the cost of flood protection increases rapidly and disproportionately with the protection afforded. For example, the maximum flood on Lake Traverse may necessitate about 10 feet of storage on the lake. The 15-year flood may require a storage of only 2 or 3 feet.

Lands worth $60 per acre, exclusive of buildings, would still be worth about $40 per acre if subject to a crop loss once in 15 years. In other words, protection against the maximum flood, which would cost at least four or five times as much as protection against the ordinary flood, would increase the value of the land only about one-third.

Lands flooded every 2 or 3 years have no value for crop raising purposes. Crop lands flooded about once in 8 years would have a value of about $30 per acre, or half their full value.

The rate of interest return on the land, buildings, and equipment has a material influence on the percentage land is depreciated by one crop loss in a given number of years. Where a 6-percent interest rate is used, lands suffering one crop loss in 10 years would retain about two-thirds of their full value, whereas, when a 4-percent interest rate is used and all other elements kept the same, such lands would retain only 57 percent of their value.

Computing value of agricultural land subject to crop loss once in a given number of years

ASSUMPTIONS

Land (exclusive of buildings), not subject to overflow, per acre	$60.00
Interest and taxes—percent	5.5
Required annual return per acre	$3.30
Buildings (including dwelling) per acre	$15.00
Interest, taxes, insurance, maintenance, and depreciation—percent	12.0
Required annual return per acre	$1.80
Machinery and equipment per acre	$7.00
Interest, taxes, insurance, maintenance, and depreciation—percent	20.0
Machinery and equipment per acre—Continued.	
Required annual return per acre	$1.40
Annual labor cost of crop per acre:	
Preparing soil and seeding	$7.00
Seed	2.00
Harvesting and threshing	3.00
Required annual return per acre	$12.00
Required total annual crop return per acre on land and labor	$18.50
Required annual crop return per acre exclusive of return on capital invested in land	$15.20

ILLUSTRATION

When a crop is lost through a summer flood, the owner loses:	
Return on buildings	$1.80
Return on machinery and equipment	1.40
Return for labor preparing soil and seeding	7.00
Cost of seed	2.00
Total loss (per acre)	12.20
In order to get a return on both labor and capital invested in land, buildings, and machinery as above indicated, the farmer must get $18.50 per acre in crops each year. If he suffers one crop loss in 10 years, the return will be:	
Nine crops at $18.50	166.50
The cost of farming will be:	
9 years' cost of preparing soil, seeding and harvesting	108.00
1 year's preparation of soil and seeding	9.00
10 years' required return on buildings, machinery and equipment	32.00
Total cost (per acre)	149.00

The difference between the return ($166.50) and the cost ($149) is $17.50. This represents 10 years' return on the capital invested in land, or $1.75 per year, which, capitalized at 5.5 percent, gives the land a value of $32 per acre.

Similarly, if one crop is lost every 15 years, the land is worth $41 per acre; if one crop is lost every 25 years, the land is worth $49 per acre; if one crop is lost every 50 years, the land is worth $55 per acre; and if one crop is lost every 5 years, the land is worth only $15 per acre.

Curves can be plotted which present these relationships graphically. It is apparent that protection against frequent flooding pays much better dividends than protection against rare flooding. If we assume that farmers lose one crop every few years because of drought, hail, or other causes, then the occasional crop loss through flooding becomes still less significant.

Where the major loss from floods is confined to the depreciation of agricultural lands, and where it is desired to combine water conservation with flood protection in what will virtually consist of two reservoirs

at the same site, it is important to consider the relative value of water conservation and flood protection.

Regulation of Red Lake

Red Lake, in Minnesota, presents an unusual problem in stream flow regulation. The combined area of the Upper and Lower Red Lake is 434 square miles. The total tributary drainage area is 1,950 square miles. The ratio of land area to water area is only 3 to 1. During years of heavy rainfall, the large lake area contributes materially to run-off. During periods of drought, the lake falls rapidly due to excess evaporation over precipitation.

Outflow and Inflow

The records of outflow from Red Lake and of the level of both the upper and the lower lake are rather incomplete. Nevertheless, the available records offer a reasonable basis for computing net inflow into the lake during the last 10 years.

As a check upon the inflow derived from the outflow plus or minus the change in storage on the lake, evaporation from the lake area has been computed on the basis of the observed monthly relative humidity and wind velocity at Moorhead and the observed monthly temperature at Red Lake Falls. During the summer months, the prevailing winds in this region are from the northwest. In consequence, temperatures on the southeast side of Red Lake at Redby are materially lower than they are at Red Lake Falls. Since the warmer northwesterly winds coming past Red Lake Falls are a better index to evaporation from Red Lake than the cool lake breezes at Redby on the southeast shore of the lake, the Red Lake Falls temperatures were used in computing evaporation. A small lag in water temperature in spring and fall was estimated.

The table below gives the annual precipitation, computed evaporation, and the gain or loss in inches of depth on the water area. The temperature at Red Lake Falls was partly estimated. A coefficient of eleven was used in the Meyer evaporation formula.

Prevailing Levels

The following hydrograph of the level of Red Lake shows that the highest level reached during recent years was 1,176.6 in June 1927. This was a year of exceptionally high water in northern Minnesota. Other high-water years were 1916, when about the same stage was reached; 1905, when a slightly higher stage was reached; and 1901, when a stage of 1,176.3 was reached. Following the 1927 high water, there was good inflow during 1928 and 1929 as shown by the hydrograph.

The lowest level reached by Red Lake during the recent drought was 1.171.4 on September 30, 1934.

Beginning May 1, 1929, the lake fell rapidly and, except for spring rises, it fell continuously until the lowest level was reached in September 1934. During this period, the excess of computed evaporation from the lake over precipitation on the lake area was 61 inches, or 5.07 feet. The observed fall in lake level during this period was 4.35 feet. The outflow during the period averaged 82 cubic feet per second. This represents 1.15 feet on the lake, leaving 3.20 feet for evaporation loss, less run-off from the land area during this period.

Evaporation and Transpiration from Land Area

As a further check, evaporation and transpiration losses were computed by months for the 9-year period. The precipitation minus losses for the period, May 1, 1929, to September 30, 1934, amounted to 4.22 inches on the land area. This is equivalent to 1.22 feet on the lake area. Subtracting the run-off, 1.22 feet, from the computed evaporation, 5.07 feet, leaves 3.85 feet computed loss, as against 3.20 feet observed loss for the 5½-year period. This represents an error of only 0.32 inch a year in the computed losses from the drainage area.

Maintaining 100 Cubic Feet Per Second at Crookston

The following mass curve of inflow into Red Lake is based upon the observed and estimated outflow and the observed and estimated change in lake level. Three lines of outflow are shown.

Year	Precipitation	Evaporation	Gain	Loss	Year	Precipitation	Evaporation	Gain	Loss	Year	Precipitation	Evaporation	Gain	Loss
1921	18.37	24.12		5.75	1927	22.40	19.53	2.87		1933	17.50	31.91		14.41
1922	22.10	23.77		1.67	1928	23.30	24.28		0.98	1934	19.40	31.33		11.93
1923	16.42	24.55		8.13	1929	13.20	24.42		11.22	1935	23.00	24.94		1.94
1924	22.21	21.24	0.97		1930	17.90	27.35		9.45					
1925	25.73	21.68	4.05		1931	21.00	27.58		6.58	Mean	20.63	25.13		4.50
1926	25.79	23.22	2.57		1932	21.20	26.99		5.79					

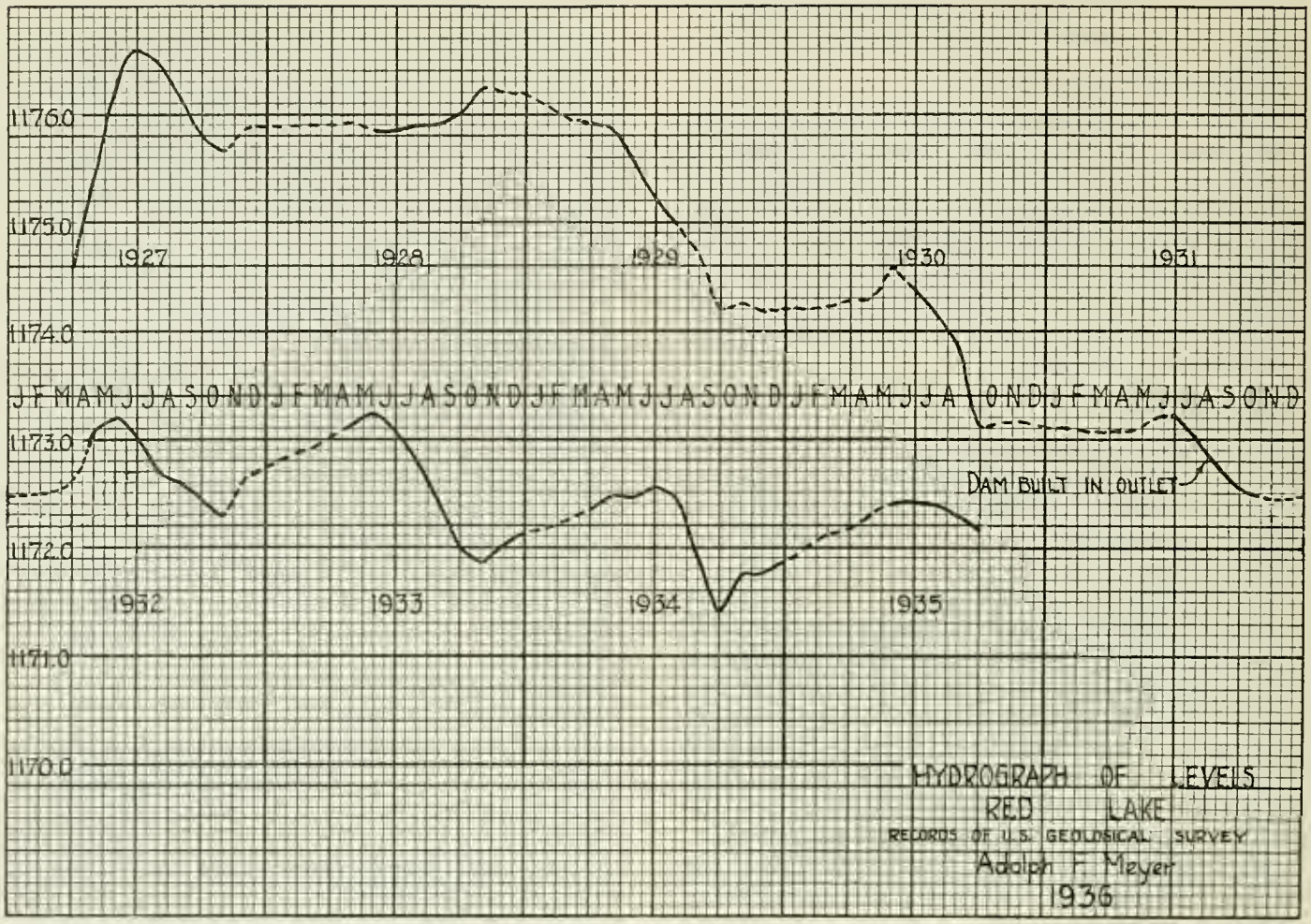
1176.0
1175.0
1927
1928
1929
1930
1931
1174.0
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1173.0
DAM BUILT IN OUTLET
1172.0
1932
1933
1934
1935
1171.0
1170.0
HYDROGRAPH OF LEVELS
RED LAKE
RECORDS OF U.S. GEOLOGICAL SURVEY
Adolph F. Meyer
1936

FIGURE 19

One line shows an actual equivalent uniform discharge over the period of 82 cubic feet per second. The second line shows the discharge from the lake as it actually occurred. The discharge was much heavier during the first part of the period. The third line shows how the outflow could have been regulated from May 1, 1939, to maintain 100 cubic feet per second at Crookston with one-half foot less fluctuation in lake level than actually occurred. If the outflow had been properly distributed over the period, the desired 100 cubic feet per second at Crookston could have been secured with an average flow of only 46 cubic feet per second from the lake instead of an actual average outflow of 82 cubic feet per second. Such regulation, of course, would have meant beginning to conserve the outflow on May 1, 1929, when the lake level was still 1,175.85. It would have meant using almost the entire storage capacity for long-time flow equalization as against annual flow equalization. Some intermediate position must be adopted.

If an ordinary maximum level of 1,175 is established on Red Lake instead of 1,174, as recommended in 1922, and if the primary aim is water conservation as against annual equalization largely for water power purposes, then a flow of 100 cubic feet per second can be maintained at Crookston without drawing Red Lake much, if any, below a level of 1,171.0 during the worst drought conditions thus far experienced and reasonably to be anticipated.

Providing for Flood Inflows

Assuming an ordinary maximum level of 1,175, the question arises as to what will happen during high-water years. Although the records are incomplete, apparently the heaviest inflow occurred during 1927. In the spring of that year, Red Lake rose a little over 2 feet. No record of outflow is available, but, judging from the lake stage and the flow at Thief River Falls and Crookston, the outflow must have averaged about 1,000 cubic feet per second for 3 months.

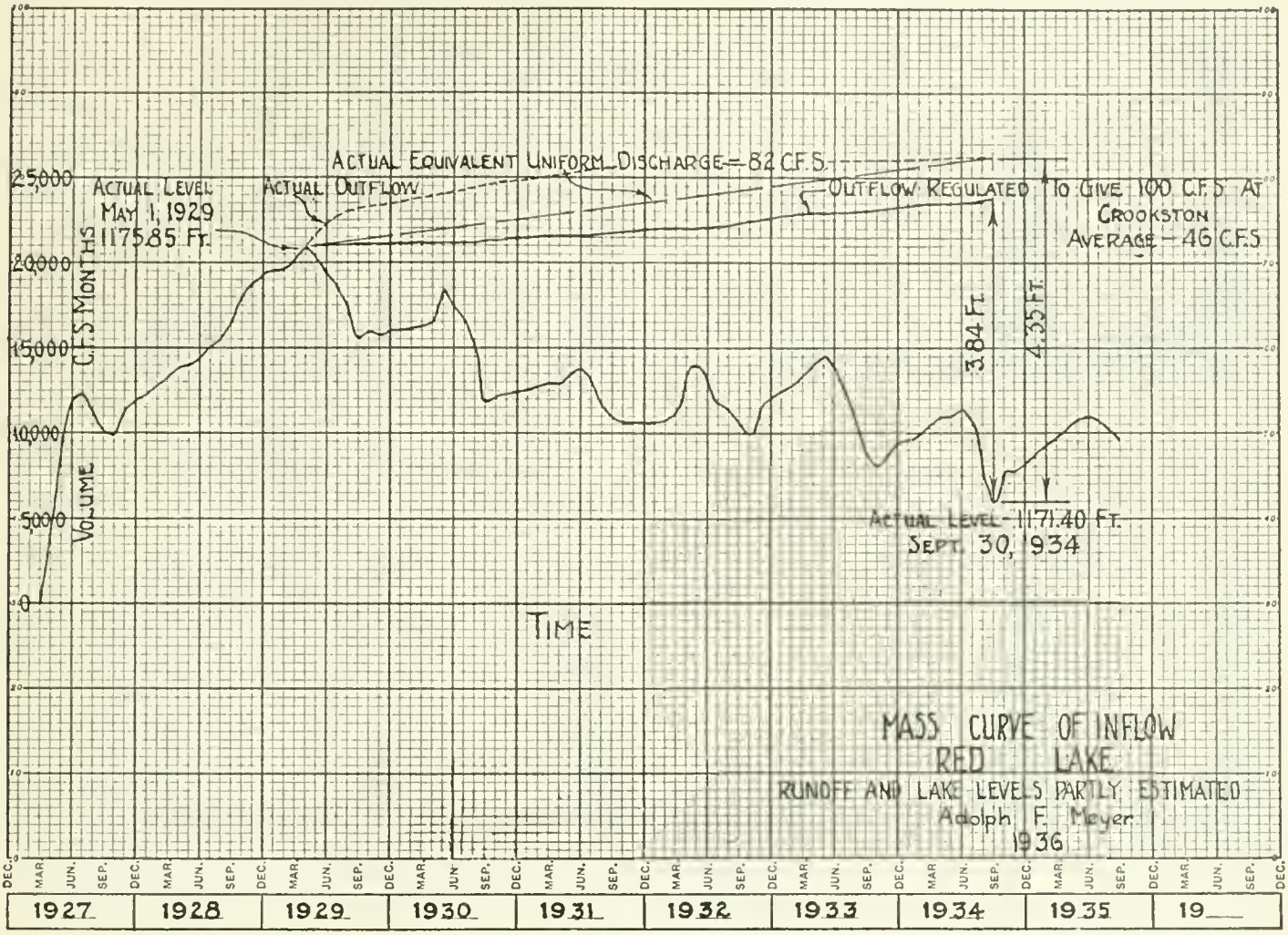

FIGURE 20

No material control of outflow from Red Lake is possible without substantial enlargement of the river channel below the lake for about 45 miles unless the lake is to be permitted to reach higher flood stages than have heretofore been recorded. Extensive channel improvement is an essential part of any water conservation plan for Red Lake.

It does not pay to protect agricultural lands from such extraordinary floods as that of 1927. Under flood conditions like those, the improved channel should be used to the utmost in order to prevent the lake from rising too high. If, for the 3 spring months, the flow had been increased to 1,600 cubic feet per second only about one-quarter foot of additional depth on the lake could have been wasted. This means that, if a regulated level of 1,175 had been maintained through the winter of 1926 to 1927, Red Lake would have risen two-tenths or three-tenths of a foot higher than it actually rose. However, all of the lakes in northern Minnesota showed heavy inflow during the fall and winter. Snowfall was heavy. Reasonable regulation of Red Lake would have demanded the release of sufficient water during the winter months to get the lake down to at least 1,174.5 by April 1. This would have provided sufficient storage capacity so that the lake could readily have been prevented from rising to a higher level than it actually did.

The inflow during 1916 could all have been absorbed in the flood reserve above 1,175 if approximately the natural outflow had been released. However, the indications of heavy spring inflow were almost as clear in 1915 to 1916 as they were in 1926 to 1927. Wasting of water could have begun during the winter, so that the lake could readily have been controlled. Similarly, in 1905 the lake could have been controlled satisfactorily if some water had been wasted in anticipation of heavy spring inflow.

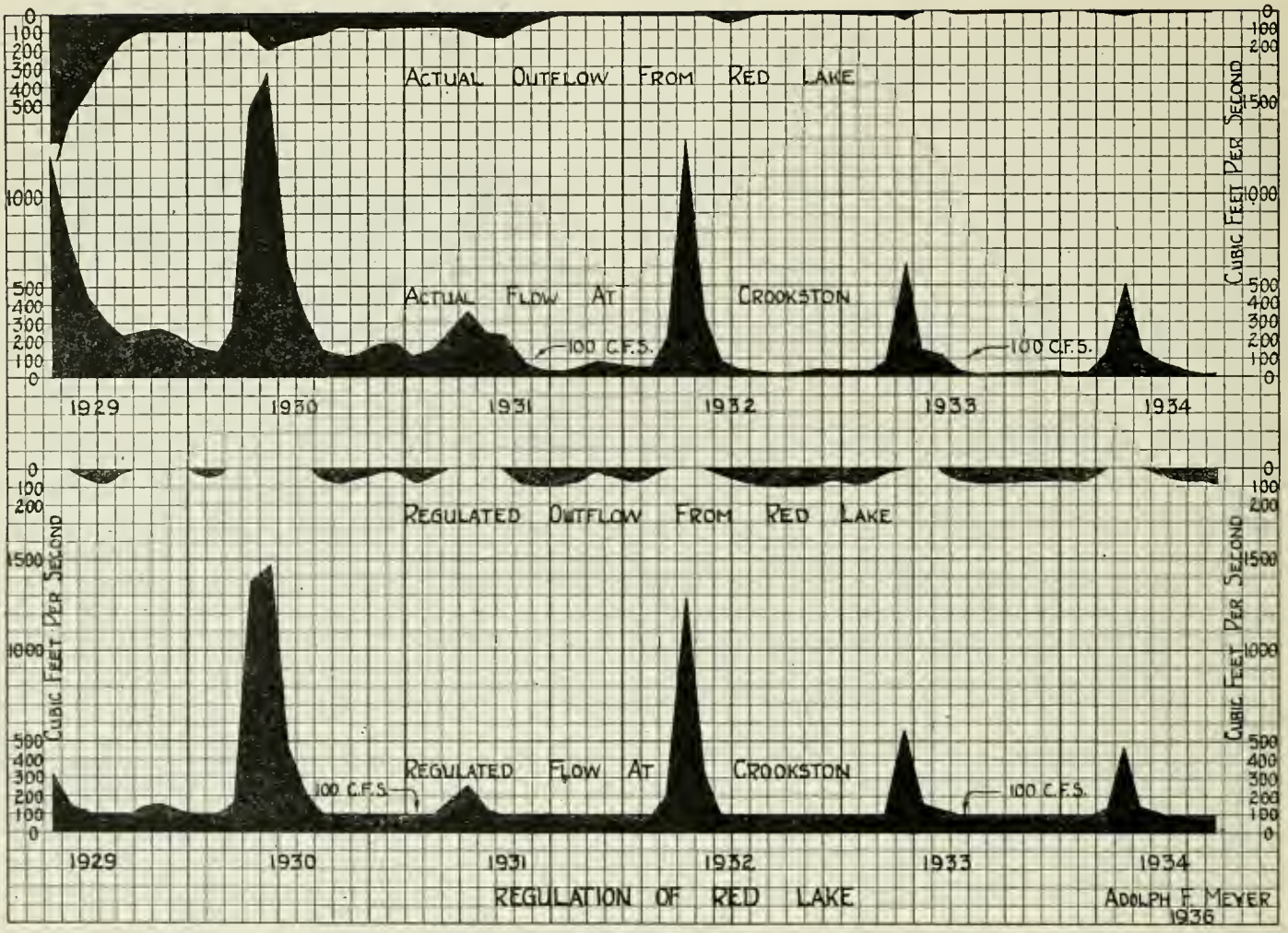

FIGURE 21

Need for Larger Low-Water Reserve

The experience since 1922 indicates the need for a larger low-water reserve than recommended at that time. It also indicates that the normal level of Red Lake should not be lowered, as appeared desirable from the viewpoint of drainage and reclamation around the Tamarack River at that time. An ordinary maximum level of 1,175 now appears more desirable than the level of 1,174 recommended in 1922. Furthermore, less annual equalization of outflow must be attempted if stored water shall be available for maintaining 100 cubic feet per second at Crookston during such an unprecedented drought period as that which we have just experienced in Minnesota.

At the beginning of the present drought period, there was no dam in the outlet of Red Lake. The rapid rate at which water ran to waste is well shown on the mass curve. If this water had been conserved, it would have been available later when badly needed.

In the upper portion of the following diagram, there is shown the actual flow at Crookston by months from May 1, 1929, to September 30, 1934, and the actual outflow from Red Lake during the same period. It was necessary to estimate the outflow during part of this period.

The lower portion of the following diagram shows what the outflow from Red Lake would have been if the lake had been regulated with a view to maintaining a flow of 100 cubic feet per second at Crookston. This regulation, of course, assumes an improved channel.

By closing the dam at the outlet of Red Lake during the spring months when there is ample water in the river below and releasing more water later in the season, the flow available for power development will also be increased. This increase, however, will not be as great as if a larger portion of the reservoir below 1,175 were available for annual flow equalization instead of being required for conserving water for use during an extreme drought period which may possibly be just ahead.

The experience of the last 9 years indicates that a relatively larger portion of the reservoir must be re-

served for storing water for use during the exceptional drought period, which may recur only once in 50 or more years, than appeared necessary in 1922. At the other extreme, we have also had heavier inflow in 1927 than during previous recorded floods. Less need exists for land reclamation and more for water conservation. Furthermore, protection of agricultural lands from infrequent floods does not pay as good a return on the cost of control works as protection from the ordinary, frequent flooding that makes crop land of little value.

Regulated Levels Proposed

According to the plan for storage and regulation here presented, an ordinary maximum level of 1320.5 would be established on Otter Tail Lake with a flood reserve of about 1.5 feet above that level and a maximum draft of about 4 feet below that level during prolonged periods of extreme drought such as that from 1930 to 1935. Whenever the lake fell below 1,319.0, the outflow would be reduced to a rate sufficient to maintain 50 cubic feet per second at Fargo. The storage between 1,320.5 and 1,319.0 could be used for annual equalization of flow as might be required, but it should be conserved to the utmost at all times when there is not a sufficient supply in sight to fill the reservoir again the following spring.

Since the regulation of outflow secured through storage in Otter Tail Lake was based on a mass curve of net inflow derived from reasonably good records of lake stage and outflow, evaporation from the lake area was automatically deducted. The computed evaporation loss during the extreme drought period from June 1, 1932, to March 1, 1935, was 43 inches in excess of precipitation on the lake area. This loss was supplied by inflow from the tributary land area. For any given month, the net inflow was equal to the outflow plus or minus the storage represented by the change in lake level. It was also equal to the gross inflow less the evaporation loss.

During the period from June 1, 1932, to March 1, 1935, the computed excess of evaporation over precipitation on Otter Tail Lake was 3.6 feet. The observed fall was 1.0 feet. The outflow during this period represents a fall of 3.0 feet, or 2.0 feet more than observed. Therefore, the gross inflow into the lake was 5.6 feet during this period.

If a draft of 4.0 feet is provided for in the plan of control, then the effective low-water storage is 3.0 feet out of a total fluctuation of 5.5 feet.

Available records do not permit a similar analysis for Lakes Lida, Lizzie, and Prairie on the Pelican River, but an effective low-water reserve of 2.5 feet can probably be secured, particularly if many of the outlying lakes in the Otter Tail Basin are also controlled.

According to the plan presented, an ordinary maximum level of 1,175 would be established on Red Lake with a flood reserve of about 1.5 feet above that level and a maximum draft of 4.0 feet below that level during prolonged, extreme droughts. In this case, also the possible regulation was based on net inflow computed from fairly good records of outflow and lake level. The critical period in this basin extended from May 1, 1929, to September 30, 1934, during which time there was 61 inches of evaporation from the lake in excess of precipitation on the lake area. The observed fall in lake level during this period was 4.35 feet. There was no dam in the outlet, and water was discharged very rapidly at the beginning of the period while the lake was high. The total outflow accounts for a drop of 1.15 feet, leaving a net evaporation loss of 3.2 feet in excess of inflow. The computed excess of evaporation over precipitation on the lake area was 5.0 feet; therefore, the inflow from the land area during the 5.5-year period was equal to 1.8 feet on the lake area, or a run-off of 1.12 inches per year.

The outlet channel improvement designed and detailed in the 1922 report is a part of the present plan.

If a draft of 4.0 feet is provided for in the plan of control, then the effective low-water storage is only 0.8 foot out of a total fluctuation of 5.5 feet.

The only practicable plan of regulation for Lake Traverse here presented contemplates an ordinary maximum level of 978 or 979 with a 5- or 6-foot flood reserve above that level and a maximum draft of 7 or 8 feet below that level during extreme drought periods of long duration.

The recent critical drought period began in July 1930, when outflow ceased. In November 1934 the lake was dry. The computed evaporation loss was 5.5 feet in excess of precipitation on the lake and inflow from the tributary land area. This would leave only about 2 feet of effective low-water storage out of a total fluctuation of 14 or 15 feet.

Interrelationship Between Precipitation and Evaporation

In studying the Otter Tail Basin, it became apparent that annual precipitation and evaporation were interrelated. Years of heavy precipitation were usually years of higher relative humidity and lower temperature and, therefore, lower evaporation loss from water areas. On the other hand, dry years were years of low relative humidity and high temperature and, therefore, higher evaporation. The result was that during wet years, precipitation exceeded evaporation from lake areas and, during dry years, evaporation greatly exceeded precipitation upon those areas. Similar effects are found upon the land areas, so that during wet years, when the lake areas do not need any support, run-off from the tributary land area overburdens the lakes with

resulting flood outflows. During dry years, when water areas cannot maintain themselves, inflow from the land areas is small and the lakes necessarily shrink.

The following diagrams show graphically the departure of annual precipitation and evaporation from the average for the period, and also the precipitation minus the evaporation, for Lake Traverse, Otter Tail Lake, Devils Lake, and for water areas in the vicinity of Bismarck, N. Dak. These diagrams clearly show the interrelationship referred to previously. There are few exceptions to the rule. The unprecedented character of the recent drought period is apparent. Unfortunately, records of relative humidity and wind velocity do not extend back far enough to permit comparing the recent drought with that indicated by the low precipitation at St. Paul between 1837 and 1856.

Regulated Flow Secured at Grand Forks

After assuming that the outflow from Otter Tail Lake and the other lakes in that basin had been regulated to secure a flow of 50 cubic feet per second at Fargo, and that the outflow from Red Lake had been regulated to secure 100 cubic feet per second at Crookston, the results of this regulation were combined to ascertain the regulated flow at Grand Forks. It was assumed that, under such extreme prolonged drought conditions as those just experienced, the river channel would be improved sufficiently to prevent any increase in the loss of water in transit, due to the higher stage.

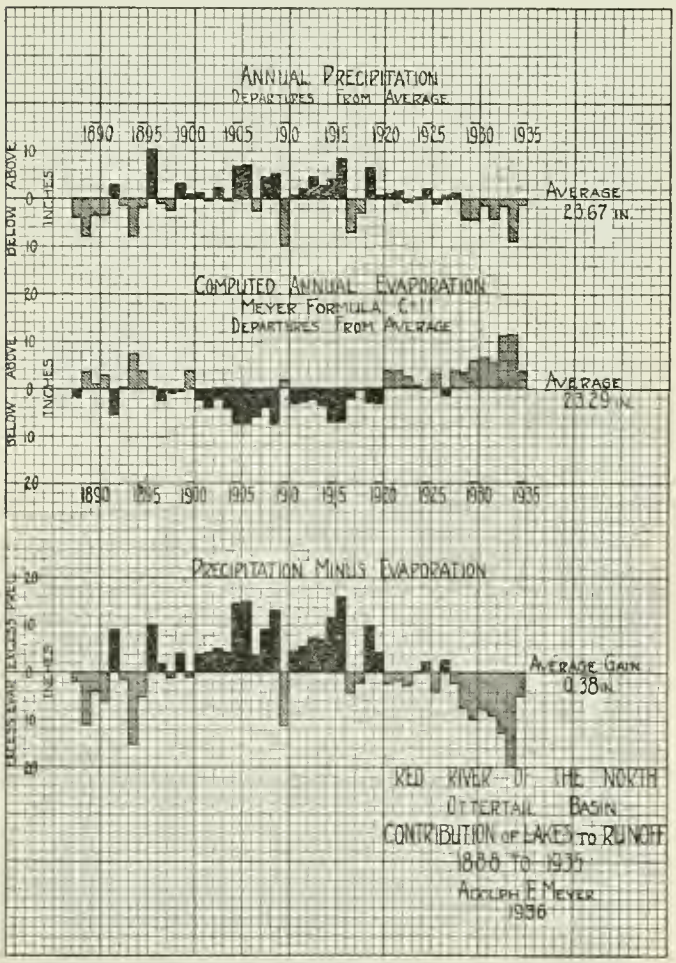

FIGURE 22

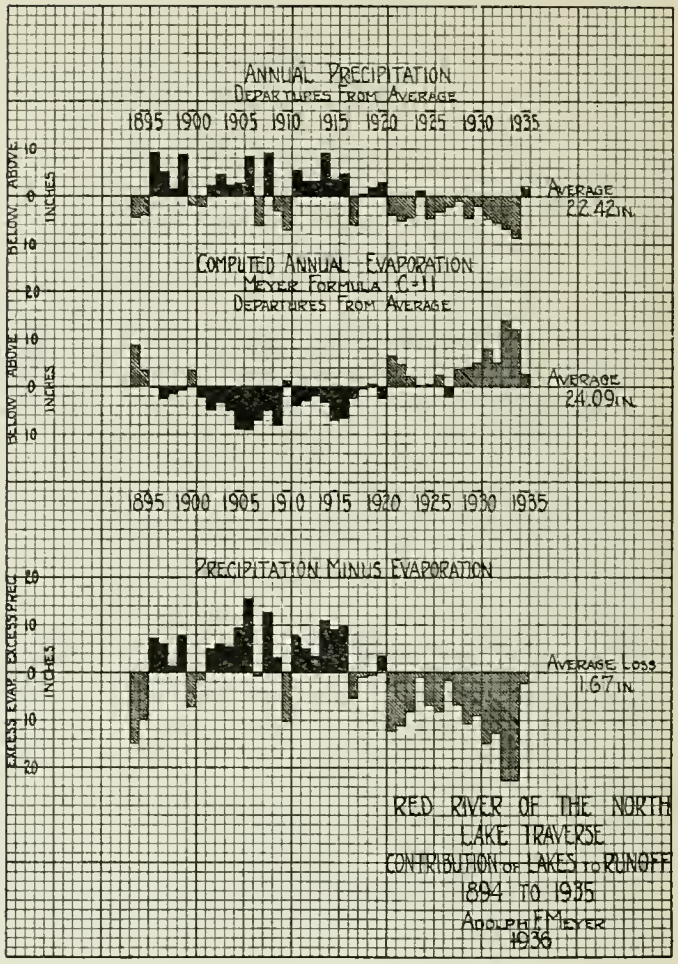

FIGURE 23

The table on page 70 presents, by months, for the crucial drought period from June 1932 to March 1935 the amount of stored water released, under the plan presented, from the Otter Tail and Red Lake Basins, and the additional amount required to produce a flow of 200 cubic feet per second at Grand Forks under such extreme drought conditions, either from about 0.1 foot additional draft on Red Lake or 2 feet of low-water reserve in Lake Traverse, or elsewhere.

Two feet of effective low-water reserve storage on Lake Traverse would have supplied this deficiency of 590 cubic feet per second months or 35,800 acre-feet. On the other hand, it could have been supplied by drawing Red Lake down only 1.5 inches more. The value of Red Lake as a regulating reservoir is so outstanding that it should be used to the utmost.

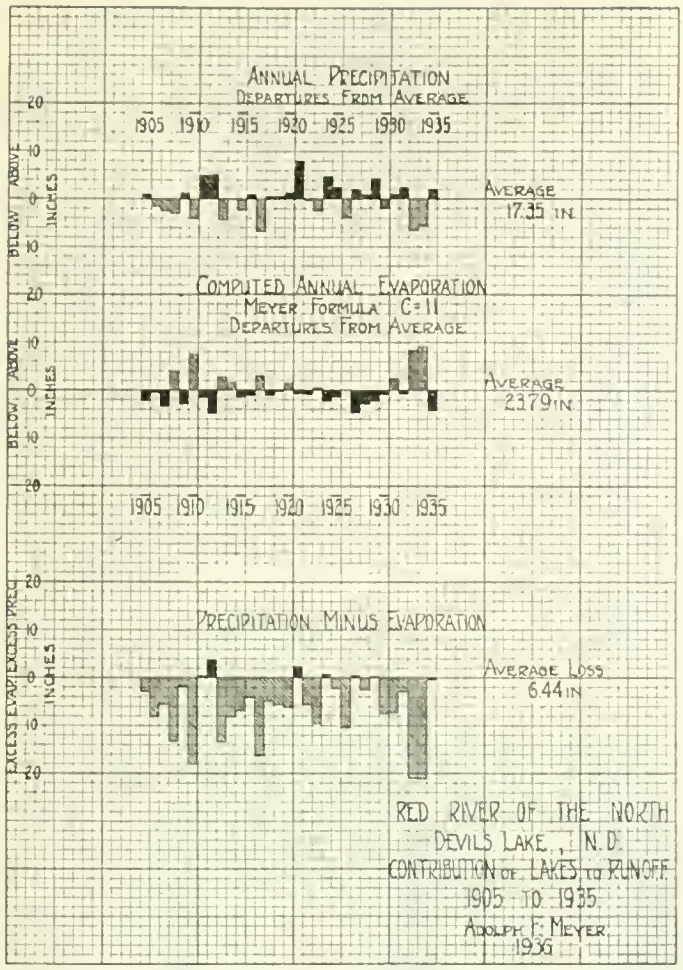

FIGURE 24

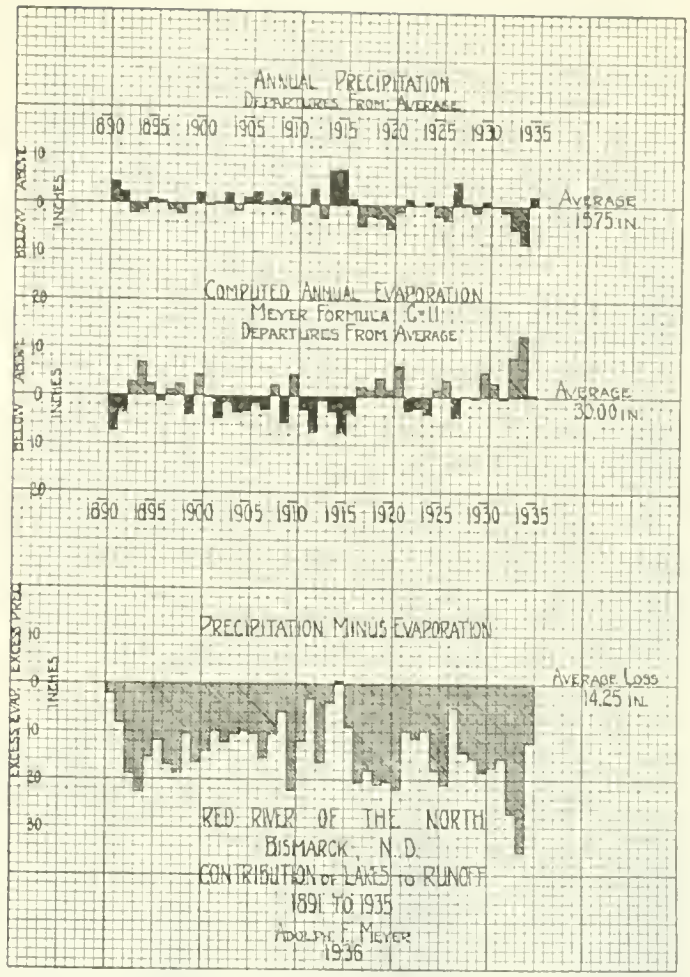

FIGURE 25

The actual flow of the Red River of the North at Grand Forks and the regulated flow secured through storage on the Otter Tail and Red Lake Basins are graphically shown on the following diagrams:

Year and month	Stored water released			Flow at Grand Forks		
	From Ottertail Basin	From Red Lake Basin	Total cubic feet per second	Present	Regulated	Required for 200 cubic feet per second
1932						
June	17	19	36	401	437	
July	42	63	105	178	283	
August	50	81	131	59	190	10
September	41	87	128	43	171	29
October	36	88	124	36	160	40
November	43	79	122	83	205	
December	48	73	121	57	178	22
1933						
January	50	77	127	39	166	34
February	50	71	121	34	155	45
March				927		
April				2,250		
May				768		
June				428		
July	35	63	98	116	214	
August	48	85	133	42	175	25
September	50	87	137	31	168	32
October	45	91	136	32	168	32
November	48	88	136	79	215	
December	37	80	117	52	169	31
1934						
January	36	84	120	39	159	41
February	30	82	112	41	153	47
March	7		7	419		
April				1,540		
May	42		42	373		
June	47	20	67	151	218	
July	50	56	106	153	259	
August	50	88	138	31	169	31
September	50	99	149	21	170	30
October	50	90	140	41	181	19
November	49	76	125	73	198	2
December	49	79	128	41	169	31
1935						
January	50	84	134	28	162	38
February	38	79	117	32	149	51
Total cubic feet per second, months	1,188	1,969	3,157			590
Acre-feet	72,000	120,000	192,000			35,800

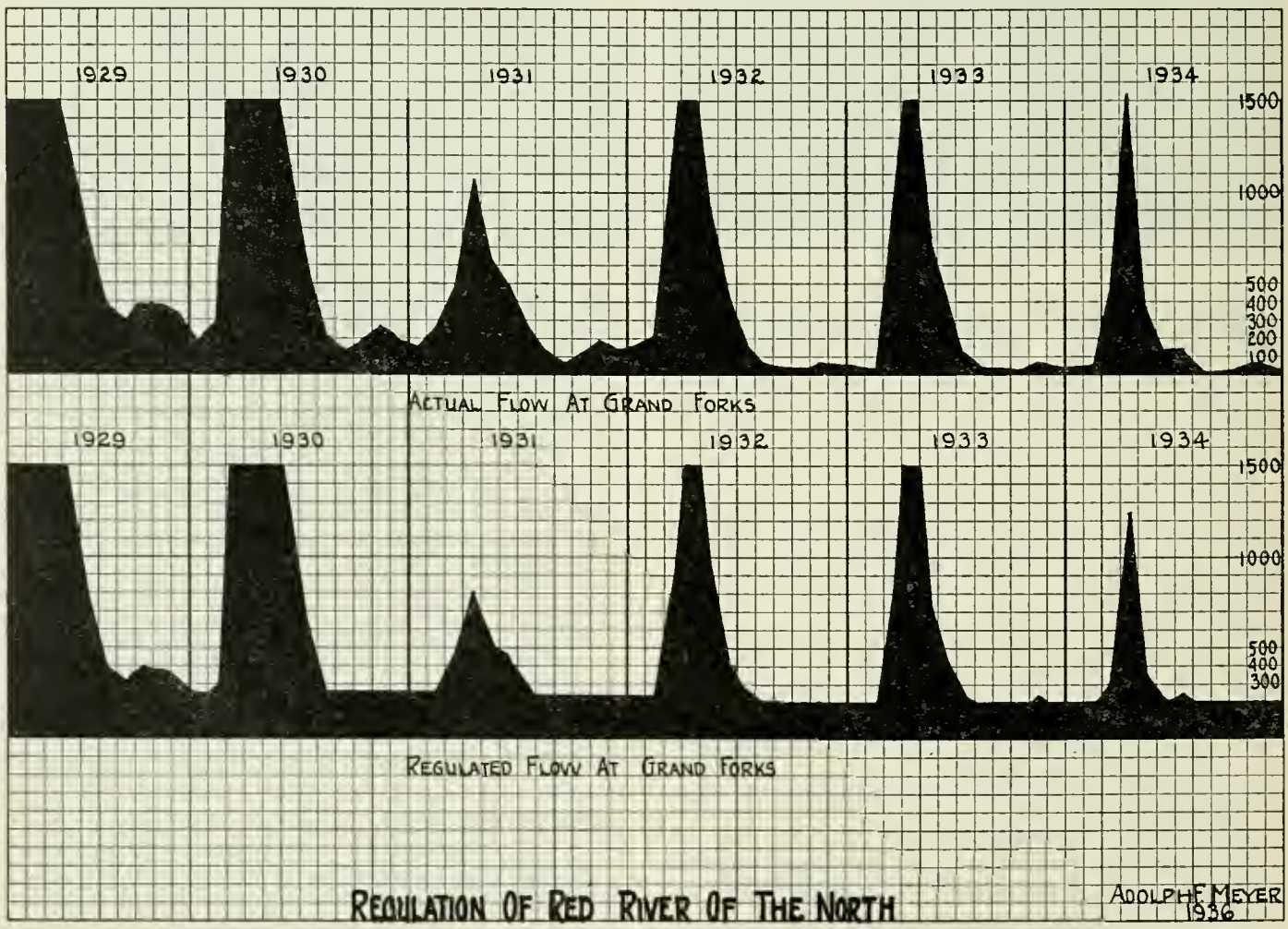

FIGURE 26

APPENDIX B—STREAM FLOW NECESSARY FOR DILUTION OF TREATED SEWAGE[2]

The calculations to follow are based on the primary assumption that all of the sewage and industrial wastes in the basin will be treated. The degree to which the sewage and wastes should be treated depends upon the dilution available, but since the amount of water needed for this dilution is likely to be the limiting factor in determining the necessary stream flows during the winter, it is necessary to assume that the treatment in use at all of the municipalities situated on the streams will be relatively complete, that is, equivalent to efficient sedimentation followed by trickling filters and final sedimentation. Such treatment is considered in these calculations as being capable of reducing the biochemical oxygen demand of the sewage 90 percent, leaving 10 percent to be disposed of by dilution.

Experience over a period of several years has shown that in shallow lakes, that is, lakes less than 20 or 30 feet in depth, the dissolved oxygen content of the water gradually decreases from the time the ice forms in the early winter until the spring break-up. In years when the period of ice and snow coverage is long, the amount of oxygen reduction may be considerable, even though the lake does not receive large amounts of sewage and industrial waste pollution. The water of the lakes in the Red River Basin is probably saturated with oxygen at the beginning of the winter, in which case it would contain about 14 parts per million of dissolved oxygen. It is estimated that during a period of 3 months, when contact with the atmosphere is prevented and when the rays of the sun cannot effectively penetrate the cover of ice and snow, the dissolved oxygen content may be reduced to 5 or 6 parts per million by natural processes alone. This means that as the winter progresses, less and less oxygen is available in the water flowing from the lakes to supply the demand of the sewage and industrial wastes.

If the best interests of the municipal water supplies are to be served there should be some dissolved oxygen—at least 2 or 3 parts per million—in the water throughout the winter in order to prevent septic conditions with the accompanying taste and odor difficulties. Fish life would also require this or a greater amount of oxygen. Considering these needs and the demands of miscellaneous sources, such as barnyard drainage, etc., it appears that by the time of the spring break-up not more than 2 or 3 parts per million can safely be assigned to supply the oxygen required to oxidize the treated sewage and industrial wastes and still provide satisfactory oxygen conditions in the stream water. The 90 percent reduction in oxygen demand considered above is rather high for everyday operation of even the best equipped sewage treatment plant, and for this reason these calculations allow a depletion of only 2 parts per million in the oxidation of the sewage and industrial wastes.

The determination of biochemical oxygen demand is ordinarily made at 20° C. and the ultimate demand at this temperature is usually considered to be satisfied in approximately 20 days. It is known that this determination is not a true measure of the rate of oxygen consumption at 0° C., which is the temperature with which these calculations are concerned. According to Phelps (Sewage Works Journal, Vol. 2, No. 4, Oct. 1930), the 1-day demand at 0° C. is only 42 percent of that at 20° C. At 5 days this ration is 54 percent, and at 10 days it is 67 percent. At this rate of increase in the ratio between the demand at 0° and the demand at 20°, the ultimate demand at 0° is satisfied in a period somewhere between 23 and 26 days instead of 20 days. Since, in this case, the sewage from any municipality is in the stream long enough for the total demand to be satisfied at any temperature, providing the oxygen is available, the total demand at 20° C. is considered as being the total demand that must be provided for in the determination of necessary stream flow.

Using 0.24 pound of total oxygen demand per capita per day, the stream flow necessary to satisfy this demand, allowing an oxygen depletion of 2 parts per million in the water, is 22.2 cubic feet per second per thousand population equivalent. With an assumed reduction of 90 percent in the oxygen demand by treatment, this figure becomes 2.22 cubic feet per second per thousand population equivalent. This would require approximately the following flows for each municipality or pair of municipalities: Fergus Falls, 25 cubic feet per second; Breckenridge and Wahpeton, 15 cubic feet per second; Fargo and Moorhead, 105 cubic feet per second; Grand Forks and East Grand Forks (exclusive of sugar factory), 55 cubic feet per second; Crookston, 15 cubic feet per second; Red Lake Falls, 3.5 cubic feet per second; and Thief River Falls, 10 cubic feet per second. Without treatment, the packing plant at West Fargo would require 1,000 cubic feet per second (estimated), and the sugar factory at East Grand Forks would require 3,100 cubic feet per second. Treatment equivalent to the 90 percent reduction specified for the municipalities would reduce these amounts to 100 cubic feet per second and 310 cubic feet per second.

It is readily seen that with no allowance for re-aeration, the necessary stream flows are cumulative as follows:

[2] Prepared by F. L. Woodward, associate sanitary engineer, and submitted by H. A. Whittaker, director, Minnesota Department of health. In the original report, this paper appeared as appendix 3. March 20, 1936.

Below Fergus Falls, 25 cubic feet per second.

Below Breckenridge and Wahpeton, 40 cubic feet per second.

Below Fargo and Moorhead, 145 cubic feet per second.

Below Sheyenne River, 145 cubic feet per second, plus the amount necessary for the Sheyenne River and the packing plant at West Fargo plus 410.

Below Thief River Falls, 10 cubic feet per second.

Below Red Lake Falls, 14 cubic feet per second.

Below Crookston, 29 cubic feet per second.

Below Grand Forks and East Grand Forks, 229 cubic feet per second, plus the amount necessary for the Sheyenne River and the packing plant at West Fargo, the sugar factory at East Grand Forks, and the packing plant at Grand Forks plus 410.

Obviously, there is some aeration in the stretches of open water and at the points where the water passes over dams. Any oxygen added to the water in this way reduces the necessary stream flow. It might be practical to provide additional aeration by designing the spillways of the dams specially for this purpose.

At the beginning of the winter, when the oxygen content of the river water is high, satisfactory oxygen conditions would be expected with flows of a third or a fourth of those given above. However, if ice forms at the lower stage, it would be impossible to provide the flows necessary for later in the season. It appears, therefore, that the ice level should be established at the higher stage.

During the seasons of open water the stream is better able to recover from the effects of pollution from one source before another source is reached, so that a stream flow of 8 to 10 cubic feet per second for each 1,000 of population equivalent of the final sewage effluent would probably provide satisfactory oxygen conditions. In periods of extreme high temperatures it is possible that somewhat larger flows should be provided, owing to the lower solubility of oxygen in water. When the river is open, the water, after recovery, can be used over and over and it is not necessary to supply at the source the total flow required by each source of pollution individually. For instance, the flow required at Breckenridge would be the amount necessary at that point without considering that needed at Fergus Falls, since it may be assumed that, under open-water conditions and with suitable treatment of the sewage and industrial wastes from Fergus Falls, recovery from the pollution contributed at that city will be fairly complete by the time the water reaches Breckenridge and Wahpeton.

It must be understood that these calculations are based entirely on oxygen resources and that the term "recovery" used above refers to recovery of the oxygen balance. Other results of pollution such as changes in the chemical constituents are not provided for. The control of bacterial pollution resulting from the discharge of domestic sewage can probably be best accomplished by disinfection of the sewage before it enters the stream.

APPENDIX C—LOSSES IN THE DISCHARGE OF THE RED RIVER ABOVE FARGO, N. DAK.[1]

Conspicuous losses in discharge of the Red River have occurred between the places of measurement at the gaging station on Otter Tail River (head of Red River) below Pelican River near Fergus Falls, Minn., and the gaging station on Red River at Fargo, N. Dak., during the low water periods of each year since 1931.

The Red River is formed by the junction of the Otter Tail River from the east and the Bois des Sioux River from the south at Breckenridge, Minn. Discharge records are available for the Otter Tail River below Pelican River, near Fergus Falls, Minn., drainage area approximately 1,900 square miles, and for the Red River at Fargo, N. Dak., drainage area, 6,420 square miles. The largest individual tributary streams in the intermediate drainage area of approximately 4,500 square miles between these places of measurement are the Bois des Sioux River which joins the Otter Tail River at Breckenridge, Minn., and the Wild Rice River from North Dakota which joins the Red River about 8 miles south of Fargo. Gaging stations are maintained on both of these tributaries; the station on the Bois des Sioux River near Fairmount, N. Dak. (drainage area, 1,460 square miles), has shown no flow since July 1930, and the station on the Wild Rice River near Abercrombie, N. Dak., has shown only a small intermittent flow.

The monthly mean discharge of the Red River at Fargo, N. Dak., and the tributary streams above Fargo for the periods of low flow during the 5 years 1931 to 1935 are shown in table 1. From that table it may be seen that during long-continued periods of low water a loss of 25 to 28 second-feet may occur in that part of the river above Fargo. A part of this loss may be caused by the use of water by Fargo and other

[1] By Charles L. Batchelder, district engineer, U. S. Geological Survey. In the original report this paper appeared as appendix 4.

TABLE 1.—*Monthly mean discharge, in second-feet, of Red River at Fargo, N. Dak., compared with sum of discharges of tributaries above Fargo to show apparent loss*

Year and month	Otter Tail River below Pelican River near Fergus Falls, Minn.	Wild Rice River, near Abercrombie, N. Dak.	Sum	Red River at Fargo, N. Dak.	Apparent loss	Precipitation at Wahpeton, N. Dak.
						Inches
1931						
July	62.6	(1)	-------	64.8	-------	3.12
August	32.3	(1)	-------	20.8	11.5	3.00
September	44.4	(1)	-------	15.6	28.8	.72
October	30.0	(1)	-------	26.6	3.4	3.15
1932						
July	32.7	0.7	33.4	7.7	25.7	1.83
August	27.2	0	27.2	0	27.2	2.90
September	31.4	0	31.4	8.8	22.6	1.55
October	24.5	0	24.5	14.1	10.4	.88
1933						
July	19.1	0	19.1	15.3	3.8	1.68
August	14.7	0	14.7	1.6	13.1	1.76
September	25.8	0	25.8	.1	25.7	.92
October	13.1	0	13.1	4.7	8.4	.05
November 16–30	21.5	0	21.5	0	21.5	.40
1934						
May	18.0	.1	18.1	8.1	10.0	.53
June	14.2	1.4	15.6	3.3	12.3	5.52
July	13.8	[2].5	14.3	0	14.3	2.38
August	11.5	0	11.5	0	11.5	2.75
September	8.0	0	8.0	0	8.0	2.03
October	11.9	0	11.9	0	11.9	1.22
1935						
July (storm)	103	[2] 10.0	113	184	-------	4.69
August	22.8	[2] 2.0	24.8	32.5	-------	3.25
September	13.9	0	13.9	8.4	5.4	.58

[1] No record. [2] Estimated.

municipalities. Assuming a total loss of 5 second-feet by municipal use where the water is not returned to the river above the Fargo gaging station, there remains a loss of 20 to 23 second-feet during some periods.

The Red River has a flat gradient and flows in a meandering course with sluggish velocity at low stages. A rank growth of aquatic plants flourishes during periods of low water in the summer. The many ox bows in the river greatly increase its length so that the river distance between the gaging station on Otter Tail River below Pelican River near Fergus Falls, Minn., and the gaging station on Red River at Fargo, N. Dak., is approximately 140 miles. Assuming the average width of water surface as 60 feet for a distance of 140 miles gives 1,018 acres of water surface subject to evaporation and transpiration losses.

The losses are not confined to the summer months, as may be seen from the records for November 1933, where the average loss for the second half of the month was 21.5 second-feet.

It may be seen from table 1 that no water passed the Fargo gaging station during the 4 months July to October 1934. As the flow of the Otter Tail River during that period was less than for some of the previous low-water periods, the apparent loss in second-feet was not as great as in other years, although the actual loss was 100 percent.

TABLE 2.—*Monthly mean discharge, in second-feet, of Red River at Grand Forks, N. Dak., and at Emerson, Manitoba, compared with summation of the discharge of Red River at Fargo, N. Dak., and the discharge of intermediate tributaries*

Year and month	Red River at Fargo, N. Dak.	Sheyenne River at West Fargo, N. Dak.	Buffalo River near Dilworth, Minn.	Wild Rice River at Twin Valley, Minn.	Goose River at Hillsboro, N. Dak.	Red Lake River at Crookston, Minn.	Sum	Red River at Grand Forks, N. Dak.	Pembina River at Neche, N. Dak.	Sum	Red River at Emerson, Manitoba
1931											
July	64.8	31.2	17.4	30.9	1.3	77.6	223.2	277	10.8	288	356
August	20.8	21.7	12.7	26.3	1.3	30.5	113.3	136	2.1	138	158
September	15.6	18.3	6.2	9.9	.3	21.1	71.4	59.5	.4	59.9	81.0
October	26.6	20.7	13.3	16.7	[1].2	34.1	111.6	111	.6	111.6	81.8
1932		59.5									
July	7.7	30.4	6.7	13.3	1.0	37.2	125.4	178	21.1	199	256
August	0	21.1	2.8	3.0	.3	19.1	55.6	58.6	6.1	64.7	62.5
September	8.8	21.2	5.7	4.6	.4	12.8	53.4	43.4	1.8	45.2	40.0
October	14.1		12.7	6.1	.5	12.2	66.8	36.0	7.5	43.5	46.1
1933		39.4									
July	15.3	17.7	9.0	19.6	(2)	36.7	120.0	116	74.5	190	253
August	1.6	12.0	7.3	5.4	(2)	15.4	47.4	41.5	27.2	68.7	73.0
September	.1	11.9	7.8	4.9	(2)	13.3	38.1	31.3	28.9	60.2	45.9
October	4.7		15.3	12.0	(2)	8.8	52.7	31.7	47.2	78.9	48.8
1934		56.2									
May	8.1	25.2	28.5	70.1	2.0	154	318.9	373	154	527	663
June	3.3	14.7	15.1	26.8	2.8	80.4	153.6	151	67.7	219	196
July	0	9.6	4.1	8.0	1.2	44.2	72.2	153	19.9	173	138
August	0	9.0	1.4	4.8	1.4	12.3	29.5	30.6	1.4	32.0	46.6
September	0	17.1	5.7	4.6	2.8	8.9	31.0	20.7	.1	20.8	23.8
October	0		19.4	7.8	(2)	10.5	54.8	40.6	1.7	42.3	47.1
1935											
July	184	108	40.2	132	(2)	90.3	554.5	666	62.4	728	1,080
August	32.5	137	15.0	84.7	(2)	32.1	302.2	404	23.5	428	514
September	8.4	34.2	8.7	64.4	(2)	56.7	172.4	184	14.9	199	269

[1] Estimated. [2] No record.

An average loss of 20 second-feet from the 140 miles of river would represent a loss of approximately 1.2 feet in depth during a period of a month, under the assumptions previously made as to the width of river and the area of water surface. The actual loss would be greater than the indicated depth of 1.2 feet which takes no account of the precipitation that fell on the water surface. The only explanation for the losses is that they are caused by evaporation, transpiration, and seepage.

The figures for apparent losses can be considered only as being indicative of the fact that such losses occur between the two gaging stations, and do not show how or where the losses occurred.

A serious shortage of water for domestic use occurred during the winter of 1932–33. Subsequently, the municipalities along the river have constructed several small dams in the channels of the Otter Tail and Red Rivers for the purpose of impounding water for domestic use. The effects of storage and depletion in the pools behind these dams cannot be computed, as records of operation are not available. However, the general method of operation during the summer months causes depletion of water in the pools and no additional storage. As these dams were built subsequent to the winter of 1932–33, their operation has affected the discharges only for the later years.

Table 2 shows monthly mean discharges at stations on the Red River compared with the summation of discharge of tributary streams added to the discharge at the upper stations on the Red River. The discharges of all the tributaries of Red River between Fargo and Grand Forks, N. Dak. (except the Sand Hill River where no record is available) have been added to the discharge of the Red River at Fargo for comparison with the discharge at Grand Forks. Similarly, the discharge of Pembina River at Neche, N. Dak., has been added to the discharge of the Red River at Grand Forks for comparison with the discharge of the Red River at Emerson, Manitoba. The discharges of several small unmeasured tributaries between Grand Forks and Emerson are not included in the addition to the discharge at Grand Forks.

APPENDIX D—RESOLUTION OF THE THIRD INTERSTATE CONFERENCE ON THE RED RIVER OF THE NORTH, ST. PAUL, MINN., JULY 8, 1936

Whereas, a plan for the coordinated long-term development and control of the water resources of the drainage area of the Red River of the North has been developed in the common interest of the people of the basin by a tri-state committee appointed by Governor Olson of Minnesota at a conference on the water problems of the area held in St. Paul on November 25, 1935, and has been approved by a similar conference on July 8, 1936, and

Whereas, the conference of July 7 is addressing a resolution to the Governors of Minnesota, North Dakota, and South Dakota, urging them to take immediately appropriate steps looking toward the establishment by legislative action and by interstate agreement of a permanent authority charged with the operation and control of water storage and release in the valley of the Red River of the North in accordance with the plan that has been developed and approved, and

Whereas, it is expected that local agencies within the basin will contribute equitably to the cost of constructing and maintaining the requisite works, and

Whereas, the current drought has precipitated in the life of the basin a crisis even more grave than that of the tragic year of 1934, and

Whereas, the conference notes with deepest appreciation the fact that the Federal Government is about to undertake measures of drought relief in the basin, now, therefore,

Be it resolved, that this conference respectfully urges the President of the United States to provide relief within the basin, insofar as practicable, by putting into action the program recommended and approved with a view to implementing the water plan for the basin. Relief work may thus be given enduring value; measures may be carried out that will conserve and augment the available supply of water and thus provide effective insurance against the recurrence of grave distress in future periods of drought.

Respectfully submitted.

MORRIS BYE, *Chairman,*
President, Red Lake River Development Assoc.,
Thief River Falls, Minn.
W. J. KIRKWOOD,
Mayor, City of Crookston, Minn.
DR. IRVIN LAVINE, *Consultant,*
University of N. Dak., Grand Forks, N. Dak.
PROF. ROLAND S. VAILE, *Consultant,*
University of Minn., Minneapolis, Minn.
DEAN HOLM,
Executive Secretary of the Committee.

Adopted unanimously by Third Inter-State Conference of the Red River of the North, St. Paul, Minn., July 8, 1936.

APPENDIX E—RESOLUTION BY REPRESENTATIVES OF THE STATES OF MINNESOTA, NORTH DAKOTA, AND SOUTH DAKOTA, MEETING AT FARGO, N. DAK., ON AUGUST 14, 1936

Be it resolved by the representatives of the States of North Dakota, South Dakota, and Minnesota, meeting in Fargo, N. Dak., on August 14, 1936, pursuant to the invitations of the Governors of North Dakota, South Dakota, and Minnesota, and pursuant to the resolution adopted by the Third Interstate Conference on the Red River of the North at St. Paul, Minn., on July 8, 1936, that:

(1) The legislatures of the States of North Dakota, South Dakota, and Minnesota, be requested to enter into an interstate compact by and between said States, establishing a commission to be known as the Tri-State Waters Commission, to regulate and administer the surface waters within drainage areas common to two or more of said States.

(2) Said commission be composed of representatives of the States of North Dakota, South Dakota, and Minnesota as follows:

(*a*) North Dakota's representatives shall be the State engineer (who is the ex-officio water conservation commissioner), the director of division of sanitary engineering, department of health, and the attorney general. A fourth member shall be selected by the Governor from a list of three persons nominated by the three named representatives of North Dakota.

(*b*) South Dakota's representatives shall be the State engineer, the director of the department of game and fish, and the attorney general. A fourth member shall be selected by the Governor from a list of three persons nominated by the three named representatives of South Dakota.

(*c*) Minnesota's representatives shall be the commissioner of conservation, the director of the division of sanitation of the department of health, and the attorney general. A fourth member shall be selected by the Governor from a list of three persons nominated by the three named representatives of Minnesota.

(3) The commission shall establish headquarters for the transaction of its business and elect from its members a chairman and shall appoint an executive secretary, who may or may not be one of the members of the commission.

(4) The commission shall have power to make rules governing its organization, time and place of meeting, and rules governing the transaction of its business.

(5) It shall be the duty of the commission to survey and study the various water problems relating to water supply, flood control, public health, water pollution, navigation, wildlife, irrigation, drainage, water power, recreation, lake levels and stream flow, and to formulate a program of regulation of water levels, stream flow and water pollution.

Such programs formulated by the commission shall conform to the constitutions of each of the several States concerned.

Programs and plans for works in said drainage areas prepared by State agencies or municipal agencies shall receive the approval of the commission before construction is begun.

It shall be the duty of the commission to maintain and control lake levels and stream flow with the approval of the authorized State agencies.

The commission shall have power to cooperate with any duly authorized Federal or internal agency in studies and surveys, construction, maintenance, and operation of water projects within the scope of its jurisdiction.

(6) The commission shall recommend to the legislatures of the three States legislation considered necessary to the efficient operation of the plans proposed.

(7) All costs incident to the control, maintenance, and operation of any project or projects shall be provided for by legislative action of the aforesaid States.

(8) A copy of this resolution shall be sent to each of the following:

Each member of the official committee.
Those attending the conference.
Members of the Planning Boards.
National Resources Committee.
Works Progress Administration.
Respectfully submitted.

H. H. Peterson, *Chairman,*
Attorney General of Minnesota, St. Paul, Minn.

Walter Olson,
Director, Division of Drainage and Waters, St. Paul, Minn.

O. H. Johnson,
Director, Game and Fish Commission, Pierre, S. Dak.

G. H. Entsminger,
Chairman, Water Resources Committee South Dakota State Planning Board, Chamberlain, S. Dak.

F. O. Olsen,
Mayor, City of Fargo, N. Dak.

M. O. Ryan,
Executive Director, North Dakota State Planning Board, Fargo, N. Dak.

Dean Holm,
Executive Secretary of the Committee, Minneapolis, Minn.

APPENDIX F—NORTH DAKOTA ACT CREATING A RED RIVER OF THE NORTH DRAINAGE BASIN COMMISSION

RED RIVER OF THE NORTH DRAINAGE BASIN COMMISSION

An act creating a Red River of the North Drainage Basin Commission consisting of three members, one of whom shall be the Governor and two members appointed by the Governor, to act jointly with commissions appointed for like purposes by the States of Minnesota and South Dakota with power to supervise the utilization and control of the waters of that portion of the drainage basin of the Red River of the North lying within the States of Minnesota, South Dakota, and North Dakota.

Whereas, the States of Minnesota, South Dakota, and North Dakota share the drainage basin of the Red River of the North and have a common interest in the most advantageous utilization of the surface waters of this drainage basin, in the control of the flood waters of this area, and in the prevention of pollution of these public waters, and

Whereas, action by individual States is inadequate to effectuate these purposes in a manner most advantageous to the common welfare of the people living in this drainage basin, and

Whereas, the only manner in which effective action can be taken with reference to these purposes is to create by compact between the said three States an interstate authority vested with sufficient power, and

Whereas, such an authority can best be created by the passing by the legislatures of each of said States of substantially identical bills providing for the creation of such an interstate authority.

Be it enacted by the Legislative Assembly of the State of North Dakota:

Section 1. There is hereby created a Red River of the North Drainage Basin Commission, consisting of three members to act jointly with commissions appointed for like purposes by the States of Minnesota, South Dakota, and North Dakota, to be called the Tri-State Waters Commission of said three States. Said Commission for the State of North Dakota shall consist of three members; one of whom shall be the Governor of the State of North Dakota and two members to be named by the Governor; *Provided, however*, That one of such members so named by the Governor shall be an actual resident of the Red River of the North Drainage Basin in North Dakota.

ARTICLE I

Each of the States of Minnesota, South Dakota, and North Dakota undertakes to cooperate with the other two States for the most advantageous utilization of the public waters of the drainage basin of the Red River of the North, for the control of the flood waters of this drainage basin, and for the prevention of the pollution of such waters.

ARTICLE II

To that end the said three States do hereby create a district to be known as the tri-State waters area, which shall comprise that portion of the drainage basin of the Red River of the North lying within the boundaries of the said States.

ARTICLE III

The said three States do hereby create the Tri-State Waters Commission, which shall be a body corporate and shall have the powers, duties, and jurisdiction herein set forth and such other powers, duties, and jurisdiction as shall hereafter be conferred upon it by acts of the legislatures of each of said three States concurred in, when of a character to require such concurrence, by act of Congress.

ARTICLE IV

The Tri-State Waters Commission, hereafter in this compact called the commission, shall consist of nine commissioners, three from each State, Minnesota, South Dakota, and North Dakota. The commissioners for the State of North Dakota shall not be entitled to compensation except the actual necessary traveling expenses incurred in discharge of their duties in connection with this act.

ARTICLE V

The Commission shall elect from its number a chairman and vice chairman and shall appoint and at its pleasure remove an executive secretary and such other officers and assistants as may be required to carry the provisions of this compact into effect, and shall fix and determine their duties, qualifications, and compensation.

It shall adopt a seal and suitable bylaws and shall promulgate rules and regulations for its management and control.

It may maintain one or more offices for the transaction of its business and may meet at any time or place within the said States.

A majority of the members from each State shall constitute a quorum for the transaction of business, the exercise of any powers, or the performance of any duties, but no action of the commission shall be binding unless at least two of the members from each State shall vote in favor thereof.

The Commission shall keep accurate accounts of all receipts and disbursements and shall make an annual report to the Governor of each State setting forth in detail the operations and transactions conducted by it pursuant to this compact, and shall make recommendations for any legislative action deemed by it advisable, including amendments to the statutes of the said signatory States which may be necessary to carry out the intent and purpose of this compact, and such changes in the area of the district as may seem desirable.

The Commission shall not incur any obligations for salaries, office, or other administrative expenses prior to the making of appropriations adequate to meet the same. The State of North Dakota shall not be liable in any manner for any damages, costs, or obligations by reason of any action under the operation of this act or by reason of any action or any regulation by the Tri-State Waters Commission. Each State reserves the right to provide hereafter by law for the examination and audit of the accounts of the Commission by its comptroller or other official.

The Commissioners shall meet and organize within 30 days after the effective date of this compact.

ARTICLE VI

It shall be the duty of the Commission to survey and study the various water problems relating to water supply, flood control, public health, water pollution, navigation, wildlife, irrigation, drainage, water power, recreation, lake levels, and stream flow within the tri-State waters area, and to formulate a program of regulation of water levels, stream flow, and water pollution.

Such programs formulated by the Commission shall conform to the constitutions of each of the several States concerned.

ARTICLE VII

Programs and plans for works of an interstate character in said drainage areas prepared by the State, municipal, or industrial agencies shall receive the approval of the Commission before construction is begun.

It shall be the duty of the Commission to maintain and control lake levels and stream flow within the area, but such action shall be taken only with the approval of the authorized State agencies.

The Commission shall have power to cooperate with any duly authorized Federal, State, or municipal agency in studies and surveys, construction, maintenance, and operation of water projects within the scope of its jurisdiction.

The Commission is hereby authorized to receive and to accept, and in the name of that State wherein the same is located, and water construction unit or units or control works constructed and completed by any Federal or other agency.

The Commission shall be authorized to exercise the power of eminent domain, to acquire such real and personal property as may be reasonably necessary to effectuate the purposes of this compact, and to exercise all other powers not inconsistent with the constitutions of the States of Minnesota, South Dakota, and North Dakota, or with the Constitution of the United States, which may be reasonably necessary or appropriate for or incidental to the effectuation of its authorized purposes, and generally to exercise in connection with its property and affairs and in connection with property within its control any and all powers which may be exercised by a private corporation in connection with similar property and affairs.

ARTICLE VIII

All costs incident to the construction, control, maintenance, and operation of any project shall be allocated by the Commission to benefited taxing units, which are authorized and directed to levy taxes at such times as authorized by law and in such amounts as to pay such costs in full within 2 years after such allocation. Such costs may be estimated and allocated in advance of expenditures subject to proper allowances in subsequent allocations insofar as actual expenditures may vary from estimates.

ARTICLE IX

Should any part of this compact be held to be contrary to the constitution of the State of North Dakota or of the United States such part of said compact shall become inoperative as to the State of North Dakota but all other severable provisions of this compact shall continue in full force and effect.

ARTICLE X

Emergency.—This act is hereby declared to be an emergency measure and shall take effect from and after its passage and approval.

Approved March 10, 1937.

APPENDIX G—A COMPACT BETWEEN THE STATE OF SOUTH DAKOTA, THE STATE OF NORTH DAKOTA, AND THE STATE OF MINNESOTA

This compact made and entered into by and between the State of South Dakota, the State of North Dakota, and the State of Minnesota, witnesseth:

Whereas, the Red River of the North, which has its source in the State of South Dakota, and which flows northward, forming the boundary line between the State of Minnesota and the State of North Dakota, has a drainage area which includes a portion of all three States; and,

Whereas, the surface waters in said drainage area, if properly conserved and regulated, will produce benefits common to all three of said States; and,

Whereas, the interests of the people of said three States will be best served by the organization of an interstate authority vested with sufficient power; and,

Whereas, all three States have mutual interests in the regulation and administration of said surface waters in said drainage area; and,

Whereas, it is highly desirable that there be a single agency of all three of said States empowered to further the aforesaid regulation and administration of said surface waters in the interests of all of said States,

Now, therefore, the State of South Dakota, the State of North Dakota, and the State of Minnesota do hereby solemnly covenant and agree, each with the other, as follows:

ARTICLE I

The following terms, whenever used in this agreement, shall have the following meanings, unless a different meaning clearly appears in the context:

(*a*) The term "commission" shall mean the Tri-State waters commission, the corporation created by this agreement and the acts authorizing the same.

(*b*) The term "acquire" shall mean and include construct, acquire by purchase, lease, device, gift, or the exercise of the rights of eminent domain, or any other mode of acquisition whatsoever.

(*c*) The term "Federal agency" shall mean and include the United States of America, the President of the United States of America, the Public Works Administration, the Works Progress Administration, and any and every other authority, agency, or instrumentality of the United States of America heretofore or hereafter created or established.

(*d*) The term "real property" shall mean and include lands, structures, franchises, and interests in land, including waters and riparian rights, and any and all things and rights usually included within the said term, and includes not only fees simple absolute but also any and all lesser interests, such easements, rights-of-way, uses, leases, licenses, and all other incorporeal hereditaments, and every estate, interest or right, legal or equitable, including terms of years and liens thereon by way of judgments, mortgages, or otherwise, and also claims for damages to real estate.

(*e*) The term "drainage area" shall mean the area from which surface waters drain from the States of South Dakota, Minnesota, and North Dakota into the Red River of the North.

ARTICLE II

Each of the States of North Dakota, South Dakota, and Minnesota undertake to cooperate with the other two States for the most advantageous utilization of the waters of the Red River of the North, for the control of the flood waters of this river and for the prevention of the pollution of such waters.

ARTICLE III

To that end the said three States do hereby create a district to be known as the Tri-State waters area, which shall comprise that portion of the drainage basin of the Red River of the North lying within the boundaries of the said States.

ARTICLE IV

The said three States do hereby create the Tri-State waters commission, which shall be a body corporate and shall have the powers, duties, and jurisdiction herein set forth and such other powers, duties, and judisdiction as shall hereafter be conferred upon it by acts of the legislatures of each of said three States concurred in, when of a character to require such concurrence, by act of Congress.

ARTICLE V

The Tri-State waters commission, hereafter in this compact called the commission, shall consist of nine commissioners, three from each State, appointed by each State in such manner and for such length of term as may be determined by the legislature thereof. Each commissioner shall be a citizen of the State from which he is appointed, and at least one commissioner from each State shall be a resident of the drainage area of the Red River of the North. Each commissioner may be removed or suspended from office in such manner as

shall be provided by the law of the State from which he shall be appointed. Each commissioner shall receive such compensation as may be provided by the legislature of the State he represents, which compensation shall be paid by such State. Each commissioner shall be paid actual expenses necessarily incurred in the performance of his duties as such commissioner.

ARTICLE VI

The commission shall elect from its number a chairman and vice chairman and shall appoint and at its pleasure remove an executive secretary and such other officers and assistants as may be required to carry the provisions of this compact into effect, and shall fix and determine their duties, qualifications, and compensation.

It shall adopt a seal and suitable bylaws and shall promulgate rules and regulations for its management and control.

A majority of the members from each State shall constitute a quorum for the transaction of business, the exercise of any powers, or the performance of any duties, but no action of the commission shall be binding unless at least two of the members from each State shall vote in favor thereof.

The commission shall keep accurate accounts of all receipts and disbursements and shall make an annual report to the Governor of each State setting forth in detail the operations and transactions conducted by it pursuant to this compact, and shall make recommendations for any legislative action deemed by it advisable, including amendments to the statutes of the said States which may be necessary to carry out the intent and purpose of this compact, and such changes in the area of the district as may seem desirable.

The commission shall not incur any obligations for salaries, office or other administrative expenses prior to the making of appropriation adequate to meet the same; nor shall the commission pledge the credit of any of the said States except by and with the authority of the legislatures thereof. Each State reserves the right to provide hereafter by law for the examination and audit of the accounts of the commission by its comptroller or other official.

The commission shall meet and organize within 30 days after the effective date of this compact.

ARTICLE VII

It shall be the duty of the commission to study the various water problems relating to water supply within the Tri-State waters area.

ARTICLE VIII

Plans for works on boundary waters in said drainage area prepared by the State, municipal, or industrial agencies shall receive the approval of the commission before construction is begun.

It shall be the duty of the commission to maintain and control lake levels and stream flow on boundary waters within the area, but such action shall be taken only with the approval of the authorized county or State agencies, in which such lake or stream is located, but said commission shall have no power or jurisdiction over water levels or stream flow in the Otter Tail River which is known as that portion of the Red River originating in Becker and Otter Tail Counties extending and flowing through in a southerly and southwesterly direction through the counties of Becket, Otter Tail, and Wilkin, and emptying into the Red River of the North at the junction of the Bois de Sioux at Breckenridge, Minn., and its chain of lakes and its tributaries.

The commission shall have power to cooperate with any duly authorized Federal, State, or municipal agency in studies and surveys, construction, maintenance, and operation of water projects within the scope of its jurisdiction.

The commission shall be authorized to exercise the power of eminent domain, to acquire such real and personal property as may be reasonably necessary to effectuate the purposes of this compact, and to exercise all other powers not inconsistent with the constitutions of the States of North Dakota, South Dakota, and Minnesota, or with the Constitution of the United States, which may be reasonably necessary or appropriate for or incidental to the effectuation of its authorized purposes, and generally to exercise in connection with its property and affairs and in connection with property within its control any and all powers which may be exercised by a private corporation in connection with similar property and affairs.

ARTICLE IX

The commission shall study the methods of financing the construction, control, maintenance, and operation of projects and shall recommend for enactment to the legislatures of the States concerned such legislation as will effectuate the purposes and ends of the commission.

ARTICLE X

Each State shall bear its proportionate share of the expense of the commission based on the pro rata value to such State of the activities of the commission, which expense shall be provided for by appropriation by the legislature.

ARTICLE XI

Should any part of this compact be held to be contrary to the Constitution of any of said States or of

the United States such part of said compact shall become inoperative as to each state but all other severable provisions of this compact shall continue in full force and effect.

ARTICLE XII

This compact shall become operative immediately after it has been signed by the Governor of the State of South Dakota, the Governor of the State of North Dakota, and the Governor of the State of Minnesota.

In testimony whereof the Governor of the State of South Dakota, the Governor of the State of North Dakota, and the Governor of the State of Minnesota have signed this compact in triplicate and the seal of said States have been thereunto affixed.

Done this 23d day of June, in the year of our Lord one thousand nine hundred and thirty-seven.

LESLIE JENSEN,
Governor of the State of South Dakota.
WILLIAM LANGER,
Governor of the State of North Dakota.
ELMER A. BENSON,
Governor of the State of Minnesota.

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